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IMPRIMERIE BIANCO LUNO

A Survey of some Theoretical Investigations on Ocean-Currents.

By

V. Walfrid Ekman, Lund.

1. The Editor has kindly asked me for a "general article" displaying for the use of the practical oceanographer the principles and the essential results of certain theories of ocean-currents developed by the writer. I am glad to meet this wish, so much the more since the theories in question have never been laid down in a non-mathematical form particularly adapted for the requirements of the practical oceanographer, and since to a large extent they have never been published in English.

Reference will be made as well to other authors' works bearing on the same subject. On the other hand the classical theories of V. BJERKNES will be regarded as known and will be mentioned only incidentally. These theories and their applications to practical oceanography have already been displayed in an excellent manner in English[1]). In the present article the reader should not expect to find practical rules for the numerical calculation of currents, such as have been prepared in the case of convection-currents by BJERKNES and his collaborators. The theories to be discussed here have not as yet been developed far enough for that purpose. What can be given for the present are only certain fundamental principles for comprehending the dynamics of the ocean; some general

[1]) The following works may be mentioned:—

V. BJERKNES and J. W. SANDSTRÖM, Dynamic Meteorology and Hydrography. Part I, Statics. Carnegie Inst. Publ. No. 88, Washington 1910.

B. HELLAND-HANSEN, Report on Hydrographical Investigations in the Faeroe-Shetland Channel etc. Parliam. Paper, London 1905.

B. HELLAND-HANSEN, Physical Oceanography and Meteorology; in Report on the Scient. Results of the "Michael Sars" N. Atlant. Deep Sea Exp. 1910, Vol. I.

BJÖRN HELLAND-HANSEN and FRIDTJOF NANSEN, The Eastern North Atlantic. Geofys. Publ. Vol. IV No. 2, Oslo 1926.

laws and theorems on currents which, being based on theoretical argumentation, it may prove useful to bear in mind when working up the results of empirical research; and finally some hints as to the order of magnitude of certain effects, which may for theoretical reasons be expected.

A list of the writer's own papers on the subject is to be found at the end of the article. In the text these papers are as a rule referred to by stating only the year of publication.

The rotation of the earth.

2. The dynamics of ocean-currents owes very much of its peculiar character to the rotation of the earth. Only by introducing a fictitious "Coriolean force" due to the rotation is one permitted to apply the laws of ordinary Newtonian mechanics. This Coriolean force is known to be directed at right angles to the earth's axis and to the direction of relative motion, and it has therefore as a rule a vertical and a horizontal component, which are both of the same order of magnitude. A calculation shows however (1927) that the vertical component is nevertheless of very little influence, since it works only over a comparatively short space, not exceeding the depth of the sea. It is therefore in most investigations left out of account altogether, and so also in those reported here. By the Coriolean force its horizontal component only will always be meant.

3. Another consequence of the comparatively small vertical dimensions of the sea is that in the dynamical equations it is as a rule possible to neglect the vertical component of velocity and so far to consider the motion as horizontal. By an exact calculation, which has not yet been published, it is actually proved that this simplification is permissible.

4. It is well known that a water particle, in order for it to move at a uniform velocity v in an invariable direction, must be acted upon by a constant force exactly balancing the Coriolean force. The force thus required is directed *contra solem*[1]) at right angles to the direction of motion, and its amount per unit of mass is $2\,v\,\omega \sin \varphi$, where $\omega = 0.0000729$ is the angular velocity of the earth and φ the latitude (reckoned positive in both hemispheres). The same thing can be expressed thus: If the water is acted upon by a constant force P per unit of mass, it is able to move in an invariable direction at a certain uniform velocity $v = cP$, where $c = 1/2\,\omega \sin \varphi$. This velocity is directed at a right angle

[1]) *Cum sole* = the direction of the apparent azimuthal motion of the sun; *contra solem* = the opposite direction of rotation.

cum sole from the direction of the force, and in the following it will be called the "normal velocity" corresponding to the force P. The quantity c, which will appear repeatedly in the following, is a space of time, and $2\pi c$ is the time which has been called half a pendulum day or 12 pendulum hours, i. e. 12 sidereal hours divided by sin φ. The following little table gives an idea of the magnitude of c in different latitudes. The figures in the second and in the third row give c in seconds and in hours respectively.

Table 1.

φ	1°	2°	5°	10°	20°	30°	40°	60°	90°
seconds	..	..	78800	39500	20000	13700	10700	7920	6860
hours ..	110	54.6	21.9	11.0	5.6	3.8	3.0	2.2	1.9

5. Furthermore, if a water particle is moving initially at a velocity v and is then left to itself without being influenced by any force (N.B. the Coriolean is no real force), it will continue very nearly in a circular path, describing it in the *cum sole* direction at the invariable velocity v. The radius of the circle is $r = cv$, i. e. it is equal to the distance which would be covered by the particle in about two pendulum-hours. Its order of magnitude for different latitudes is seen from the bottom row in the above table, which gives r in nautical miles if the velocity is a mile per hour. For other velocities r will vary in proportion.

Finally, if the particle has initially a velocity V and is from that moment acted upon by a constant force P per unit of mass, its subsequent motion will be a cycloidal motion made up of a rectilinear uniform motion with the "normal velocity" v corresponding to the force and of a circular motion. Fig. 1 shows how the radius of this circular motion may be found. OA is supposed to represent the initial velocity V, when the quantity c is used as a unit of time, and OB represents under the same assumption the normal velocity v. Then the radius of the circular motion is equal to AB, i. e. it is the distance which would be covered in the time c at a velocity equal to the geometrical difference between the velocities V and v.

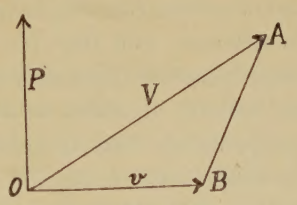

Fig. 1.

6. I have dwelt at some length on these elementary principles, because they are of fundamental importance for the whole theory. As a rule the forces acting on an individual quantity of water are altering steadily, though more or less slowly. The motion will then at any time be

made up of the normal velocity, corresponding to the simultaneous force, and an infinite number of superimposed infinitesimal circular motions. As a rule the amplitude (i. e. the radius) of the resultant circular motion will mainly depend on the alterations of force experienced during the last few pendulum-hours, since the older contributions will be more or less cancelled owing to differences of phase and will be gradually extinguished by viscosity. The consequence is that the circular motions will be quite insignificant, or in other words that the velocity may at any moment be supposed to be normal[1]). In an acute form this important principle can be emphasized as follows: The force does not, as in Newtonian mechanics, determine the acceleration but the velocity of the current. The water-masses of the ocean are in motion when impelled by a force, and they come to rest at the same moment as the force ceases to act; and when the force changes, the velocity of the water immediately experiences a corresponding change. This statement sounds paradoxical, but becomes intelligible when it is remembered that the pendulum-day should be considered as a small (infinitesimal) space of time. Occasionally, in the treatment of particular questions, which shall be mentioned later on, the pendulum-day is not an insignificant space of time, and it is not permissible to consider the velocity as normal.

7. The influence of the earth's rotation on ocean-currents was conceived long ago and is generally regarded as a well-known fact. But if conceived merely qualitatively without any regard to the quantitative relationship it is easily misunderstood. Thus, for instance, one can read even in some of the very best treatises that the ocean-currents owing to the earth's rotation have a tendency to turn to the right in the northern hemisphere, and that for this reason the Gulf Stream off the North American coast gradually turns from a northerly or northeasterly towards an easterly direction of motion. The idea expressed by such statements is apparently that the water, after having attained its greatest velocity in the Straits of Florida, proceeds by its inertia, but — owing to the earth's rotation — in a path bent to the right. As soon as the amount of the effect is considered it becomes immediately evident that this idea cannot be a correct one. The path of the current between the Straits of Florida and Newfoundland has on the average a radius of curvature of, say, about a 1000 miles. However, if the water had moved by its inertia alone, the curvature of the path would have been enormously greater.

[1]) This is the very same principle on which HELLAND-HANSEN, in a remarkable paper of 1905 (*loc. cit.* p. 295), made the theorem of BJERKNES available for the calculation of the actual velocities of convection-currents.

On the latitude of Florida ($\varphi = 25°$) and with a maximum velocity of 5 miles an hour the radius would have been 23 miles, and in an average latitude $\varphi = 35°$ and with a velocity of a mile an hour it would have been $3^1/_3$ miles only! As a matter of fact the effect of the earth's rotation on the inertial motion is — from a geographical point of view — to annihilate it and not to bend its path; and the direction of the current in each particular part of its path depends merely on the wind and the pressure-gradient at the spot.

Amount of current.

8. Consider a unit area in the sea-surface and with it as base a vertical column of water reaching right down to the bottom. The total momentum of this water-column, i. e. its mass multiplied by the velocity of its centre of gravity, defines the sum total of the transport of water (the direction of the transport included). It is called the "amount of the current" (die "Strommenge"). Although this article is intended as much as possible to do without mathematics, the mathematical expression for the amount of current ought to be mentioned. It is a directed quantity S just like a velocity and is defined by its components S_x and S_y in two horizontal directions x and y. If the components of velocity in the same directions be denoted by u and v, the density of the water by ϱ, the depth below the sea-surface by z, and the depth of the sea by d, S_x and S_y are expressed by the integrals

$$S_x = \int \varrho u dz; \qquad S_y = \int \varrho v dz,$$

the integration being extended from 0 to d.

The importance of the notion is connected with the following property: Imagine two vertical lines extended from the surface to the bottom and situated at unit distance from one another in one vertical plane perpendicular, say, to the axis of x. Then S_x is equal to the total mass of water passing in unit time between the two verticals towards the side facing the positive direction of x (any mass of water, that happens to move in the opposite direction, being reckoned negative).

The simple relationship between a force and the corresponding normal velocity of a water-particle has its exact parallel in the relationship between the sum total of forces impelling a column of water and the "amount of the current". The latter is directed at right angles *cum sole* from the direction of the former, and the two quantities are in the same proportion c to one another, as was mentioned in § 4.

Turbulence.

9. The motion of the water in the sea is turbulent, i. e. irregular eddies are superimposed on the mean-motion — which in most cases is alone of immediate interest to the oceanographer — and materially influence it by producing an intense exchange of matter and of motion between the different layers of water flowing on top of one another. It is a process analogous to the irregular motions of the individual molecules; and just as these cause molecular viscosity in a liquid performing smooth motions, the turbulence gives rise to "eddy-viscosity". The important difference is that the latter is in most cases enormously greater than the molecular viscosity, and it is much more variable, depending in a high degree on the nature of the mean-motion itself. The combined effect of molecular viscosity and turbulence is expressed by what has been called the "virtual coefficient of viscosity".

10. Much of the uncertainty of theories of ocean-currents is due to the fact that so little is known about the real magnitude of this quantity. It must be expected that it would be smaller where the density of the water is decreasing upwards than in homogeneous water, since in the former case all vertical motions of turbulence are restrained by the stable equilibrium. This has been verified experimentally (1906), but there is little chance of determining by such small-scale experiments how much the eddy-viscosity will be reduced under given conditions in the sea. In any case it must be expected that the eddy-viscosity will be very much reduced in a pronounced discontinuity-layer.

Furthermore it must be expected that the eddy-viscosity is much reduced in the neighbourhood of the sea-surface and of the sea-bottom, since there the eddies have too little room to be well-established. An accurate consideration of this circumstance would involve a very great complication; in the case of bottom-currents however, allowance can be approximately made for it by means of a simple artifice.

In reality the downmost water-layer sticks to the bottom so that it has there no motion at all, but on the other hand the rate of vertical increase of velocity is greatest there. Now leave out of consideration altogether a thin water-layer nearest to the bottom (the "skin-layer"). The rest of the water is then running at a finite velocity over the bottom. The artifice rests upon the hypothesis that this slip-velocity is connected with a "skin-friction" acting between the sea-bottom and the downmost water-layer, so that the skin-friction would be equal to the square of the slip-velocity multiplied by a certain constant coefficient of skin-friction k. The motion would in this way depend upon two coefficients, *viz.* k and the virtual coefficient of viscosity μ, the latter being assumed

to have a constant value in all levels above the neglected skin-layer. In the case of the analogous problem of winds it has been shown[1]) that in this way rather good agreement could be obtained between observed and calculated motions. In the case of ocean-currents the method has not been used very much yet, but reference can be made to papers by JEFFREYS[2]) and by the present writer (Eddy-Viscosity etc. 1928). A further account of this matter will be given below in connection with particular problems of currents.

Type problems and actual problems.

11. Owing to their complicated character it would be utterly impossible to calculate exactly the motions of the ocean and the atmosphere. In order to make dynamical oceanography (and meteorology) treatable it is necessary therefore to simplify its problems materially. This has been done in two essentially different ways. One way is to replace the actual external conditions — as e. g. the shape of the ocean-basin, the winds, the distribution of temperature and salinity — by simplified imagined ones and to treat, from a dynamical point of view, as exactly as possible the resulting simplified problems. This method might be called the method of type problems, and the greater part of the results here reported have been obtained by it.

Another way is to consider as exactly as possible the observed external conditions, but to simplify the problem from a dynamical point of view, as e. g. by neglecting viscosity (and eddy-viscosity). The well-known theory of V. BJERKNES and his collaborators is characteristic of this method, which might be called the method of actual problems.

Neither method would alone satisfy the requirements of practical oceanography. For it would be impossible to solve a series of type problems covering the wide range of actually occurring conditions; and on the other hand the less accurate solutions of actual problems badly need to be checked by a comparison with the exact solutions of similar type problems. Especially it is obvious that currents, which are entirely or partially due to the winds, cannot be accounted for by a theory which neglects viscosity. A series of suitably chosen type problems would however, when solved, serve as a framework about which, by less accurate methods, a theory comprising changing reality may then be safely formed.

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[1]) G. I. TAYLOR, Eddy Motion in the Atmosphere, London, Phil. Trans. Roy. Soc. A, *215*, 1914, p. 1.

[2]) H. JEFFREYS, On the Effect of a Steady Wind on the Sea-Level near a Straight Shore, Phil. Mag. London, *46*, 1923, p. 114.

12. The theories, which are to be reported here, essentially aim at two different problems. The first problem has for its object the state of motion in one geographical locality — or strictly speaking along one vertical — only. The wind and the vertical distribution of density, as well as the slopes of the sea-surface and the boundary surfaces between the various layers of equal density are all supposed to be known, and the problem is to calculate the direction and velocity of the current at all levels along the vertical. The comprehension of all these directions and velocities is called the "local elementary current".

The currents, however, influence the distribution of density and the slope of the sea-surface and are again reacted upon by them, and so the second problem arises: to calculate the final positions of all these surfaces within a region of the sea, and particularly to calculate the slope of the sea-surface, since it cannot be determined by any methods of observation available. For the present there cannot be any question of a real solution of this problem, but investigations in this direction seem to have produced certain oceanographical laws of some interest.

Pure drift-currents.

13. The simplest and the oldest problem of an elementary current is that of a "pure drift-current", i. e. the current produced by the wind blowing over the exactly horizontal surface of homogeneous water. Originally the problem was solved (1902 and 1905) only under the assumption that the virtual coefficient of viscosity has a constant value from the surface downwards. The result, though perhaps known, may be shortly recalled to mind, but it is sufficient to dwell on the case of deep water, the case of shallow water being of inferior interest.

The velocity of the surface-water is, under the said assumptions, directed at 45° *cum sole* from the direction of the wind, and with regard to the deeper water-layers this angle increases uniformly with the distance below the surface. At the same time the velocity decreases according to a geometrical law — in the proportion $e^{-\pi} = \frac{1}{23}$ for each time its direction has turned through two right angles. If from equidistant points in a vertical line arrows be drawn representing the direction and velocity of the current at their respective depths, they will therefore appear in the form of a spiral staircase, the breadth of the steps decreasing rapidly downwards as shown in Fig. 2. In this figure the uppermost feathered arrow should represent the wind. If the arrows be drawn at infinitely short intervals their points would form a curve, the horizontal

projection of which (indicated in the figure as seen from the side) is an "equiangular" spiral.

The deviation of the current does not follow immediately on the setting in of a new wind, but only a few hours are required, and after the lapse of this time its direction and velocity will for some time be oscillating to both sides of their final values. The surface-current will have passed for the first time through its final direction within 5 pendulum hours (about 6 hours in the North Sea).

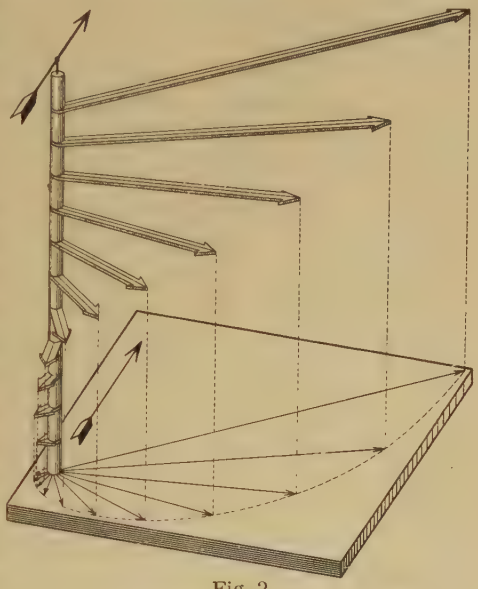

Fig. 2.

14. The vertical distance, in which the direction of motion turns through two right angles — that is the distance between the levels of the uppermost and the downmost arrow in Fig. 2 — is called the "depth of frictional influence"[1]), since it signifies in a way a limit to the vertical distances within which a horizontal motion can be transferred by friction (when disregarding velocities short of 5 % of the original one). It is denoted by the letter D, and it is connected with the virtual coefficient of viscosity μ according to the formula

$$D = \pi \sqrt{2c\mu/\varrho},$$

where ϱ denotes the density of the water and c the quantity defined in § 4. Owing to the factor c it increases towards the equator inversely proportionally to the square root of the sine of the latitude, when other conditions remain unaltered.

The above-mentioned assumption of "deep water" really implies that the depth of the sea should exceed the depth of frictional influence, since otherwise the motion would be materially modified by friction against the sea-bottom. In the open ocean this assumption is amply fulfilled, for the depth of frictional influence would rarely exceed 200 metres except in very low latitudes.

[1]) A briefer, more concise English name for this quantity (like the German „Reibungstiefe") would be highly desirable.

15. As was mentioned in § 10 the assumption of a constant virtual coefficient of viscosity μ is not in accordance with facts, and so far the description in § 13 and 14 of a pure drift-current is a fiction only. Its lack of truth is not however very serious. It was proved (1906) that, independently of any variations of μ along the vertical, the velocity will steadily diminish from the surface downwards, and at the same time turn in the *cum sole* direction. The spiral is therefore always established. The difference is that it will not, in horizontal projection, be equiangular, and that the deviation of the surface-velocity will not be exactly 45°.

The quantity D defined by the equation in § 14 still keeps its dynamical significance, but since it generally varies along the vertical one must resort to an average value of it as an expression for the depth of the current. This average value of D, calculated for the region of the surface-current, has been denoted by D' and called the "upper depth of frictional influence". It increases of course towards the equator and — owing to the intenser turbulence — with the strength of the wind. It could be calculated approximately from oceanographical observations if one knew the relationship between the velocities of wind and current. There has been some divergence of opinion as to the exact law of this relationship, but modern investigations[1]) seem to be in favour of a direct proportionality between the velocities of wind and current. If this be true, there would be a direct proportionality as well between these velocities and D'. According to the writer's calculation (1905) D' would be equal to the distance covered by the wind in 7 or 8 seconds divided by the square root of the sine of the latitude. In the case of high latitudes (70° or more, say) this would give the following round values of D' in metres for different winds measured in the Beaufort scale of 12 degrees:

Beaufort	1	2	3	4	6	8	10
D' metres	15	25	35	50	75	110	155

In lower latitudes these values of D' should be multiplied by 1.1 for $\varphi = 55°$, by 1.2 for $\varphi = 45°$, by 1.4 for $\varphi = 30°$, by 2 for $\varphi = 15°$, by 3 for $\varphi = 6°$ etc.

Also the surface-velocity V_0 of the pure drift-current was found to be inversely proportional to the square root of the sine of the latitude, being, according to a preliminary estimation, in high latitudes equal to 0.0127 times the velocity of the wind. From this another useful relationship was deduced (1923) viz. D' should — independently of the geo-

[1]) An interesting paper on the subject was published by C. S. Durst in Quart. Journ. Roy. Met. Soc. vol. 50, London 1924.

graphical latitude — be 600 times the surface velocity of the pure drift-current, i. e. it should be equal to the distance covered by this current in 10 minutes. It should be unnecessary to point out that this and similar formulae mentioned here cannot at best be regarded as more than approximations.

16. As was mentioned in § 8 there is a simple relationship between the "amount" of a current and the sum total of forces impelling a vertical column of water. This has an important application to drift-currents in deep water, since in this case the tangential stress exerted by the wind is the only external force impelling the water. Thus, for instance, an easterly wind would on the northern hemisphere give rise to a transport of water exactly from the south towards the north, and the amount can be calculated if the amount of the stress is known.

According to calculations by the present writer (1905) and by G. I. TAYLOR[1]) — the former referring to a storm on the Baltic and the latter to varying winds over Salisbury plain, but both giving conformable results — the stress in C. G. S.-units exerted by the wind should be about 0.032 times the square of the wind-velocity in metres per second, the coefficient 0.032 being 10000 times the coefficient of skin-friction between the air and the water-surface.

For example, suppose that the wind-velocity is 10 m. per sec. (i. e. nearly 6 Beaufort), and that the latitude is 40°. Then the tangential stress of the wind is 3.2 C. G. S.-units, and from the table in § 4 one will find $c = 10700$, so that the amount of the drift-current would be $3.2\ c = 34000$. That means: if a straight line of 1 cm. in length be drawn in the direction of the wind, and if from its end-points verticals be drawn right down to the bottom, a net transport of 34000 grams or approximately 34000 cm^3 of water will in each second pass between the two verticals.

Slope-currents.

17. Currents produced in the various parts of the ocean without regard to the want of compensation would necessarily cause various parts of the sea-surface to rise or fall, and this would be the case with the pure drift-currents produced by the varying winds. Hence the necessity of investigating the currents produced in homogeneous water when the sea-surface is inclined to the horizon.

There has been some confusion with regard to the denomination of such currents. Since they are immediately produced by a horizontal

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[1]) G. I. TAYLOR, Proc. Roy. Soc. London, A. *92*, 1916, p. 196.

pressure-gradient[1]) the writer originally denoted them by the name of "gradient currents". Subsequently, it has become customary in meteorology to apply the terms "gradient wind" and "gradient velocity" to the wind and wind's velocity which would exist in absence of friction. Adopting this convenient notation in oceanography as well, where it will prove to be useful, the term "gradient current" should be reserved for the current produced by the actual pressure gradient in the absence of friction. This is a notion which always refers to a particular level in a particular locality. Now we are dealing however with the currents produced in homogeneous water, in all levels between the bottom and the surface, when the latter is inclined to the horizon. We cannot do without a name for them, but I have had some difficulty in finding a suitable English word ("Staustrom" in German). In this article they will be denoted as "slope currents", but I would not propose to keep to that name, if a better one could be found.

18. The slope-currents are influenced by friction from the sea-bottom, just as the drift-currents are influenced by friction from the surface. In the one case as in the other therefore the "depth of frictional influence" enters as a fundamental quantity, but its magnitude may be different in the two cases, since the generation of turbulent eddies may be either more or less intense within the bottom-layer as compared to the surface-layer. In analogy with the "upper depth of frictional influence" D' characteristic of the pure drift-currents, we have in the case of slope-currents to do with a "lower depth of frictional influence", which has been denoted by D''.

19. In the case of slope-currents two different regions should be distinguished: above and below a level at the distance D'' from the sea-bottom. Above that level friction is insignificant, and the current is simply a gradient-current: it is directed at right angles *cum sole* from the direction of slope, and its velocity, which will be denoted by G, is proportional to the angle of slope γ.

$$G = gc\gamma,$$

where c is the quantity defined in § 4 and g the acceleration of gravity. Suppose, for example, that off the Norwegian coast in 60° N there is on some occasion a slope towards West of 2 in a million (which would make 68 cm from Norway to the Shetlands). The gradient-current would

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[1]) As may be known, this word is used to denote at the same time a direction and a quantity, *viz.* the horizontal direction of greatest decrease of pressure and the decrease of pressure per unit length in this direction.

then run from south to north at the velocity $G = 980 \times 7920 \times 0.000002 = 15.5$ cm. per sec.

Below the said level the velocity is reduced by friction from the sea-bottom, and the arrows representing the direction and velocity in different levels will appear in the form of a spiral staircase like that which characterized the pure drift-current, though turned upside down. Fig. 3 is intended to illustrate this under the assumption that the depth of frictional influence is a constant, in which case the points of the arrows, when projected on a horizontal plane, lie on an equiangular spiral. Correspondingly there may be said to be a "bottom-current" reaching to the level D'' (denoted by a D in the figure) and above it a uniform "deep-current".

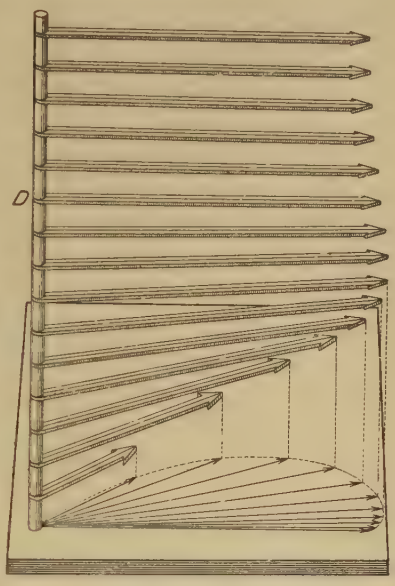

Fig. 3.

20. As is seen from the figure, a transport of water more or less in the direction of slope takes place within the bottom-current only. This is a fact with important consequences. For the water-transport in the direction of slope has alone the effect of restoring the equilibrium of the sea-surface, when differences of level have been produced.

Unfortunately circumstances are not so favourable for calculating this water-transport, as they are in the case of pure drift-currents. If the virtual coefficient of viscosity had been a constant within the region of the bottom-current, the amount of the current in the direction of slope would have been approximately equal to the velocity of the gradient-current multiplied by $D''/6$ (1/6 being an approximation for the density of the water divided by 2π). But we have no means as yet of determining by observations the quantity D'', as could be done with the "upper" depth of frictional influence D'. The only attempt that has been made at an estimation of D'' is merely a hypothesis founded upon the analogy with the pure drift-current (1923). In § 15 it was mentioned that D' might be estimated as 600 times the surface velocity of the pure drift-current. By analogy it is a short step to assume for D'' the value $D'' = 600$ times the velocity G of the gradient-current.

21. The circumstances become still more unfavourable for another

reason. The virtual coefficient of viscosity certainly varies along the vertical, and this will influence the amount of the current, but we do not know the exact law. It is true the latter difficulty may probably be surmounted to some extent by means of the artifice of "skin-friction" described in § 10. But in any case this method would imply the necessity of determining two unknown constants in the theory of slope-currents. In § 16 a value 0.0000032 was given for the coefficient of skin-friction in the air. For theoretical reasons it is assumed that this coefficient should be proportional to the density of the fluid, and for water it would then be about 0.0025, which is in good agreement with the results of hydraulic experiments.

The consequences of the notion of skin-friction in the theory of ocean-currents are being investigated, and it would be premature to enter on the matter in detail here. It may be sufficient to mention that the water-transport in the direction of slope would — except in very low latitudes — come out markedly smaller than it would under the assumption of a constant virtual coefficient of viscosity and no slipping at the sea-bottom; from the above-mentioned value of the coefficient of skin-friction and under certain reasonable assumptions the reduction has been calculated to be in the ratio 0.7 in a latitude of 5°, in the ratio 0.5 in 20°, in the ratio 0.4 in 40° and approximately in the ratio 0.35 in latitudes of 60° or more. This may be mentioned in order to indicate in what direction the theory is likely to be altered in the future. In any case, however, the most serious cause of uncertainty about the point in question is the fact that the order of magnitude of the "lower depth of frictional influence" is unknown.

22. The combined result of a wind and an inclination of the sea-surface will be a pure drift-current and a slope-current superimposed, and in the case of sufficiently deep water (the depth exceeding the sum of the upper and the lower depth of frictional influence) three different currents may be distinguished running on top of one another. The bottom-current, which is a constituent part of the slope-current, reaches to the height D'' above the sea-bottom. The space between this level and a level at the distance D' from the surface is occupied by the gradient-current alone. This is the current which the present writer in 1905 called the "midwater-current", but which in conformity with a notation subsequently adopted in other languages I would prefer to call the uniform "deep-current". As a rule it will occupy the greatest part of the space between the bottom and the surface. On top of the "deep-current" a "surface-current" will run, the velocity of which is in each particular

the resultant of the velocities of the gradient-current and the pure drift-current.

23. As was already indicated above, one of the components of this system of currents, viz. the slope-current, will be automatically developed so as to satisfy the condition that the total quantity of water carried by the slope-current and the drift-current into any region of the sea must be equal to the quantity carried out of it.

In the 1905 paper some conclusions were drawn from this fact with respect to the currents in the neighbourhood of a long, straight coast. Here of course the total flow (the amount of the current) in a direction normal to the coast must be *nil*. The result was found to be a deep-current parallel to the coast and proportional to the component of the winds velocity in the same direction. The velocity G of the deep-current would be $\sqrt{2}$ times the surface velocity of the pure drift-current, multiplied by the cosine of the angle between the directions of the wind and the coast.

We will take an example. Suppose that in winter time a westerly wind is blowing with a velocity of 10 m. per sec. in a latitude of 40° off the North American Atlantic coast, which has here a main direction towards N 30° E. The surface velocity of a pure drift-current produced by a 10 metres per sec. wind would according to § 15 be 12.7 cm. per sec. at the poles and 16 cm. per sec. in 40° N. Multiplying by $\sqrt{2}$ and by cos 60° we obtain finally 11 or 12 cm. per sec. as the velocity of the deep-current. This calculation however was made from the views of the 1905 paper viz. that the lower and the upper depths of frictional influence were equal. However, if we use the assumption $D'' = 600\,G$ (§ 20), the amount of the slope-current at right angles to the coast will be in proportion to GD'', i. e. to the square of D'', and on this assumption the velocity of the deep-current would be found to be 13 or 14 cm. per sec. If furthermore the very reasonable assumption of slipping and skin-friction at the sea-bottom (§ 10) be introduced, the results will be once more altered. According to the views expressed in § 21 a greater velocity of the slope-current would then be required in order to produce the same transport of water in the direction of slope so that on this account the velocity of the deep-current would be more than doubled. All these alternative calculations and complications are communicated with the sole view of exemplifying the difficulty and uncertainty which are, in the present state of the theory, connected with the actual calculation of drift-currents.

24. The currents here described can, after the setting in of a new wind, arise only gradually and comparatively slowly. For they require

a wedge of water to be formed, the volume of which is obviously proportional to the angle of slope and to the square of the breadth of the current; and all this water must be transported by the pure drift-current, which in addition must continuously compensate for the water carried off by the bottom-current already established. An approximate estimation gave the result that the times required for this purpose are rather insignificant (a fraction of a day, only) within, say, 100 kilometres distance from the coast, but that they may amount to weeks, when the breadth of the current exceeds 500 km.

Furthermore it should be remembered that the deep-current, immediately on the establishment of a slope, will at first run down hill and only gradually takes its final direction along the level-lines of the sea-surface, thus receiving during its down-hill run the kinetic energy of the resulting steady motion. Although this down-hill run is of very small duration (a few pendulum-hours only) it may indirectly be of importance. For if the depth is great, it may during the short time carry off a considerable quantity of water, and this must be supplied by the pure drift-current, which owing to its smaller thickness has only very limited efficiency. It was calculated that for this reason the establishment of the deep-current must be further delayed by a time, which — when reckoned in pendulum-days — would be of an order of magnitude equal to the ratio between the depth of the sea and the depth of frictional influence.

Distortion of deep-currents.

25. The theory of 1905 so far considered the influence of the continents, as to observe that the total flow of water across the coast line must be *nil*, but otherwise conditions were assumed to be uniform within the region considered, so as to allow a current to have in each particular level the same velocity and direction everywhere within the region. This assumption is however only rarely justified and must be abandoned, and here the theory of 1923 comes in. It would be difficult without mathematics to explain exactly its various conclusions. It may be sufficient first to explain them in principle without regard to quantitative laws and then, without demonstrations, to give an account of the latter and their oceanographical consequences.

Obviously any circumstance, which causes a local accumulation of water in one part of the sea and removal of water from another, will give rise to alterations of the sea-surface and the slope-currents. If winds and other external circumstances are stationary, this alteration will go on, until for every part of the sea equilibrium between inflow and outflow has been restored.

26. A few examples, represented graphically in Fig. 4, will suffice to illustrate the general character of slope-currents produced by a depression or by an elevation of the sea-surface respectively. The faint lines represent the stream-lines of the gradient-current, and on them arrows are drawn with heavy lines to represent the velocities. If we keep to the northern hemisphere, the diagrams in the upper row all represent currents produced by a depression of the surface, the diagrams in the lower row currents produced by an elevation; and *vice versa* in the case of the southern hemisphere. As a help in the descrip-

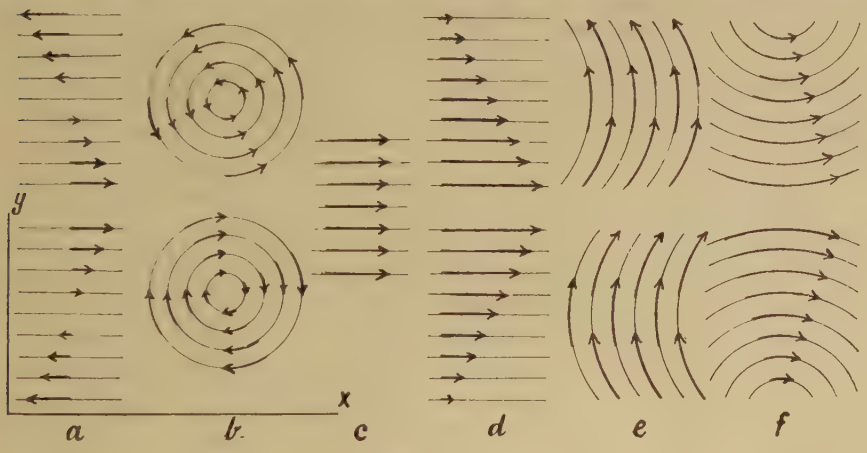

Fig. 4.

tion of the diagrams, which should of course be considered as horizontal, two directions: x and y are put in.

The two diagrams a represent gradient-currents produced by a cylindrical depression or elevation in the shape of an endless straight groove or ridge in the direction of x, a cross-section of the sea-surface having the form of an arc of a circle or parabola. (In the case of these as well as of the following diagrams allowance is of course made for the curvature of the geoid itself, and the sea-surface being cylindrical simply means that its height above or depth below the geoid-surface is constant in the direction of x.) The diagrams b represent the currents produced by a circular depression or elevation, within which the surface forms a small part of a very great spherical surface.

The single diagram c represents the homogeneous field of a gradient-current produced by a uniform slope of the sea-surface in the direction of y. By superimposing on this uniform slope the cylindrical depression or elevation represented in a, gradient-currents are produced as shown in diagrams d. On the other hand the diagrams e represent the result

of superimposing the above-mentioned depression or elevation on a uniform slope in the reverse direction of x.

Finally the diagrams f represent the result of superimposing on the uniform slope c the circular depression or elevation b.

All these diagrams illustrate the general law, very easily deduced mathematically, that a depression of the sea-surface causes a rotational motion *contra solem* and an elevation a rotational motion *cum sole*. The rotational intensity or "vorticity" is mathematically expressed by means of the differential expression $\partial v/\partial x - \partial u/\partial y$, where u and v denote the components of velocity in the directions of x and y.

27. It is not necessary however to dwell on these mathematical expressions; it is sufficient to illustrate by examples the significance of another quantity viz. twice the quotient between the velocity and the

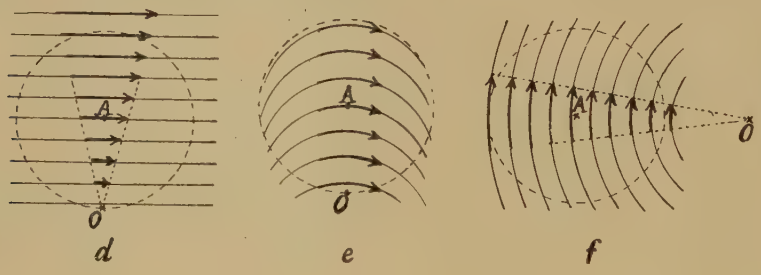

Fig. 5.

vorticity. This quantity has the dimension of a distance. We shall call it the "radius of rotation" and denote it by L.

First consider a case of motion characterized by rectilinear stream-lines as in the case of Fig. 4, diagrams *d*. Imagine the velocities in the neighbourhood of a point A to be represented by arrows in the usual manner (Fig. 5, *d*). The value of L at the point A is then equal to twice the distance to a point O, from which all these arrows are seen under equal angles. Next consider a motion under which — as in the case of Fig. 4 diagr. *e* — the amount of the velocity is invariable in the neighbourhood of a point A (Fig. 5, *e*). The value of L at this point A is then equal to twice the distance to the centre of curvature O of a stream-line passing through A. Finally suppose that the stream-lines are curved, and that at the same time the amount of the velocity is variable. In this case both the above-mentioned operations may be performed and as a rule give two different distances AO; it can be proved that either of them may be greater or smaller than $\frac{1}{2}L$, but that L is never smaller than the smaller distance AO. Fig. 4, f and 5, f represent a limiting

case, in which the two operations give one distance AO, which is then equal to the radius of rotation L. In the three diagrams in Fig. 5 dotted circles are drawn with their centres at A and with $\frac{1}{2}L$ as radius. In all three cases the current is seen to present considerable differences of direction or of velocity or of both inside the circles, and as a matter of fact this is a general rule (provided the vorticity is everywhere within the circle of the same order of magnitude). In other words: a current is not even approximately homogeneous inside a region, the linear dimensions of which are of the order of magnitude L or more.

28. Our next care must be to examine the various agents and circumstances which, by causing elevations and depressions of the sea-surface, have the effect of producing rotational deep-currents.

The most effective agents would be the deep-currents themselves, if they converged towards or diverged outwards from a region of the sea. They are however almost entirely eliminated and for the following reason:

The deep-current, being a gradient-current, flows at right angles to the direction of slope. A convergence of deep-currents towards a region A (Fig. 6) would therefore imply a slope round this region, so that when circumnavigating it in the direction of the arrow one would return to the point of departure at a lower level than the original one, which is impossible. Of course this argumentation does not prove that an accumulation of water within a region A cannot take place, for such an accumulation might very well be the net result of the water flowing into the region from one side and out of it to the other side at a lower velocity. A simple mathematical calculation, based on the very same principle as the argumentation above, proves however the impossibility (in a sea of uniform depth) of such a net amount of inflow or outflow, if the velocity of the gradient-current is proportional to the angle of slope of the sea-surface. In § 33 we shall come back to the latter reservation and its real purport.

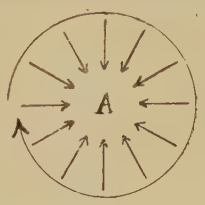

Fig. 6.

Other agents are rain and evaporation. A detailed calculation (1926) has shown, however, that they are of very little consequence for the deep-currents, and for the present they may be safely left out of account altogether.

29. Of much more consequence is the "anemogeneous effect" caused by the winds. It must be remembered that a wind produces a flow or "amount of current" not in its own direction but at right angles to it.

A circuit of winds blowing *cum sole* round a region will therefore give rise to an elevation of the sea-surface there, and similarly a circuit of winds blowing *contra solem* will produce a depression in the centre. In both cases the final result will be a circuit of deep-currents following the same direction (*cum sole* or *contra solem* respectively) as the winds. The bottom-currents are of course directed so as to carry off the quantities of water accumulated here and there by the pure drift-currents.

On this point a possible cause of mistake should perhaps be removed at once. A circuit of winds blowing *cum sole* requires a high atmospherical pressure in the centre, and this will cause a corresponding depression of the sea-surface. It should be remarked that this depression does not imply a pressure-gradient in the sea directed towards the centre, which might partially or entirely cancel the effect described above. On the contrary this depression has chiefly the effect of restoring in the sea the equilibrium which is disturbed in the air.

There is approximately a proportionality between the vorticities of the deep-current and the wind producing it. But this does not however imply a similar relationship between the radii of rotation in the water and in the air, for the radius of rotation depends on the velocity as well. If the lower and the upper depth of frictional influence were equal, and if the velocity of the deep-current were $\sqrt{2}$ times the surface-velocity of the pure drift-current (as would be the case off a straight coast with the wind blowing parallel to it), the radius of rotation would be the same in the deep-current as in the air, and there would be some evident resemblance between a chart of the currents and a chart of the winds. But in most cases the velocities of the deep-currents will probably be much smaller, and then the radius of rotation would come out smaller in the same proportion.

30. Next consider the "topographic rotational effect" i. e. the effect due to differences of depth. Assume the surface over a part of the sea to be plane and sloping so as to involve a uniform pressure-gradient. Allowing for differences of latitude within the region the latter will produce a gradient-current of everywhere the same direction and velocity. Consider a part of the region limited by two vertical planes parallel to the gradient-current and by two at right angles to it. Fig. 7 may represent a length-section parallel to the former planes and ending in the cross-sections at *A* and *B*. The deep-current is supposed to flow in the

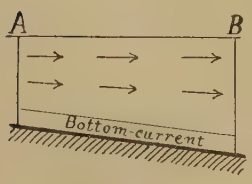

Fig. 7.

direction from A to B. A length-section transmits no water except within the region of the bottom-current, and here exactly equal quantities of water flow in from one side and out to the other. The cross-sections transmit all the water of the deep-current; and if as in the figure the depth at B is greater than at A, the intermediate region will continually lose quantities of water proportional to the difference of depth and to the velocity of the current. According to what has already been explained regarding the result of a depression or an elevation of the sea-surface, a deep-current running in the direction of increasing depth will therefore experience a rotation *contra solem*; and similarly when running in the direction of decreasing depth it will experience a rotation *cum sole*. It will be understood from the diagrams in Fig. 4 that this rotation may imply either a deflection of the stream-lines, or a decrease of the velocity to one or the other side, or both.

31. One might easily expect that this effect would depend essentially on the relative differences of depth, so that e. g. a descent of the sea-bottom of 500 m. in 5000 metres' depth would influence the currents just as much as a descent of 100 m in 1000 metres' depth. As a matter of fact it would have been so, if the slope-currents produced by displacements of the sea-surface had in their entirety been effective for restoring its horizontal position of equilibrium. But we have seen that this levelling effectiveness of the slope-currents is due to the bottom-currents alone and therefore independent of the depth of the sea. The consequence is that the topographic rotational effect depends — under the assumptions hitherto made — on the absolute differences of depth; so that a bottom-ridge of, say, 100 metres' height would influence the currents just as much if the depth is 5000 m., as if it is 1000 m. As for the reservation inserted here it will be discussed in § 36.

The magnitude of the effect has been calculated mathematically and may be expressed as follows: Let D'' denote the lower depth of frictional influence and l the distance — reckoned along the stream-lines of the deep-current — in which the depth alters by an amount equal to D''. Then the radius of rotation L of the deep-current is equal to l/π or approximately equal to $l/3$; so that a bottom-ridge of a height D'' or more, or a bottom-groove of the same depth, would be an almost insuperable obstacle for the current.

32. Fig. 8 is intended to illustrate this topographic rotational effect in a case where the deep-current is not allowed to follow the level-lines of the bottom. The lower part of the figure represents a vertical section of a sea in northern latitudes with its bottom traversed by alternating ridges and channels after the pattern of corrugated sheet-iron. The

ridges are supposed to be perpendicular to the section. The upper part of the figure represents a type of undulating stream-lines which the deep-current would under these circumstances be able to follow. Their average direction is right across the ridges, and from this average direction the velocity bends alternately to the right and to the left, its maximum deviation to the right being immediately above the ridges and the maximum deviation to the left above the channels. The angular magnitude of the deviation depends on the height of the corrugations and has been constructed, as is indicated in the figure, on the assumption that this height is $\frac{1}{2} D''$ only, from the channel to the ridge.

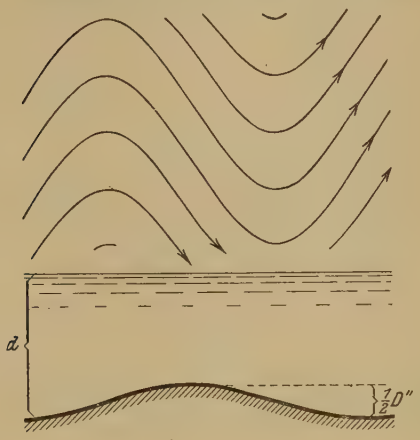

Fig. 8.

A calculation of the velocities of the currents is of interest. Imagine that the currents represented in Fig. 8 are indirectly produced by a given wind blowing off a long coast, which is extended in the same main direction as the section in the figure. The velocity of the slope-current is then determined by the condition that it should carry away from the coast an equal quantity of water as is carried towards the land by the pure drift-current. On this assumption it is found that the velocities of the deep-current would come out smaller in the particular case of Fig. 8 than in a sea of uniform depth, the average velocity (in the direction of the coast) being reduced by 55 %, and even the maximum velocity (i. e. where the stream-lines form the greatest angle with the coast-line) would be reduced by 16 %. If the bottom-ridges had been 4 times as high (2 D'' reckoned from the channels) the velocities would have been very forcibly reduced by 95 % and 70 % respectively.

This effect is very easily explained. For it is seen from the figure that the deep-current is (in the particular case) directed out from the land where the depth is maximum and towards the land where it is minimum; with the result that the deep-current itself will materially contribute to the removal of the water from the coast; and this of course implies that a smaller velocity of the slope-current in general will be sufficient than if the bottom-current alone had to be responsible for the transport. This argumentation can indeed be applied generally, to

the effect that irregularities of depth as a rule result in a reduction of the velocities of the deep-currents.

33. There is one more circumstance to be taken into account as a cause of rotational deep-currents. The argumentation in § 28 rested on the condition that the velocities of the deep-currents are proportional to the angles of slope of the sea-surface. But this condition is not exactly satisfied, since the velocities produced by a given slope increase (proportionally to the quantity c) from the poles towards the equator.

To examine the consequence of this fact we will consider as in § 30 and Fig. 7 a region limited by two vertical planes parallel to the gradient-current and by two planes A and B at right angles to it (Fig. 9), and assume that the sea-surface can be regarded as plane and the pressure-gradient as constant. But this time we will assume the sea-bottom to be horizontal, and we will take into account the differences of latitude within the region. Suppose that the deep-current is flowing, say, from lower towards higher latitudes. Then its velocity is greater in A, where it enters the region, than in B where it leaves it. For similar reasons the bottom-current as well may carry either more or less water into the region than out of it, namely if the direction of the gradient-current (deep-current) is not exactly parallel to the meridian; but this difference is of inferior importance on account of the comparatively small capacity of the bottom-current.

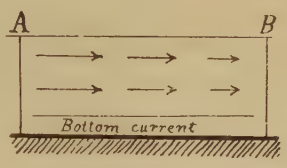

Fig. 9.

As an approximate result it can be said, therefore, that a slope-current will cause a rise or fall of the sea-surface approximately proportional to the depth of the sea and to the meridional component of the deep-current towards the pole or the equator respectively. In consequence the deep-current will experience a rotation *cum sole* when directed towards increasing latitudes and *vice versa*.

Further calculation has shown that this "planetary rotational effect" is greatest in tropical regions, being inversely proportional to the trigonometrical tangent of the latitude. How considerable it is in low latitudes will be understood from the following example. The latitude is assumed to be 15° and the depth of the sea to be 10 D'' only, which will probably mean something considerably less than 3000 metres. The radius of rotation, which comes out approximately independent of the velocity, would then for a gradient-current directed due south or north be no more than 56 km.!

34. The actual course of the currents will be the compound result

of the anemogeneous, the topographic, and the planetary rotational effects. The relative importance of the three components essentially depends on the velocity of the deep-currents as compared to that of the pure drift-currents; for the anemogeneous rotational effect depends upon the field of pure drift-currents, whereas the two other components depend upon the directions and velocities of the deep-currents themselves. If the velocities of the latter are very small in comparison with the surface-currents, the anemogeneous effect may be more or less decisive with regard to their courses. If however the deep-currents, though of course weaker than the surface-currents, are nevertheless of a similar order of magnitude, an estimate based upon charts of average winds shows that the anemogeneous rotational effect is as a rule of comparatively little consequence. As a matter of fact the two other components — the topographic and the planetary — may then involve such an intense distortion as practically to prevent the formation of any deep-currents of more than merely local character, if they considerably deviate from the particular direction for which the rotational effect is *nil*. An approximate idea of the courses taken by the currents could therefore be obtained by expressing mathematically the condition that the resultant topographic and planetary effects should vanish altogether.

It was remarked above that this manner of argumentation would not be applicable to cases in which the deep-currents are very slow as compared with the surface-current — a remark which may be of importance, and which is emphasized here because it was not made in the original paper. Such slow deep-currents would however, in a way, be of inferior interest, inasmuch as they would not appreciably affect the motion of the upper water-layers; and they are not taken into account in the investigations reported in the present article. It should also be emphasized here that the velocities of the currents have throughout — and particularly in the argumentation in § 28 — been assumed to be normal, or in other words that the acceleration of the water has been disregarded. With this reservation the principal results of the analysis may be summed up as follows:

35. In high latitudes (where the planetary effect is of comparatively small influence) the deep-currents would follow the level-lines of the sea-bottom, in any case where the slope of the sea-bottom is appreciable.

In very low latitudes (where the planetary effect is dominating) the deep-currents would be restricted to easterly and westerly directions. The same would be the case in all places where the level-lines of the sea-bottom run east and west.

In other places the deep-currents would form a definite angle α with the parallels of latitude, so as to run at the same time either towards increasing depths and increasing latitudes or *vice versa* and so as to satisfy a certain relationship between the angle α, the latitude φ, the depth, and the slope of the sea-bottom in the direction of the current. This relationship is illustrated by Table 2 below, giving for various values of φ and α the distance - reckoned in kilometres along the deep-current — in which the depth increases or decreases by ten per cent.

Table 2.

	$\alpha = 10°$	20°	30°	40°	50°	60°	70°	80°	90°
$\varphi =$ 5°	321	163	111	87	73	64	59	57	56
10°	648	329	225	175	147	130	120	112	112
20°	..	678	463	361	303	268	247	235	232
30°	..	..	735	572	480	425	391	373	368
40°	..	..	..	832	698	617	569	543	534
50°	..	..	..	..	991	877	808	771	759

The range of the table is limited to values of the tabulated quantity below 1000, since higher values would correspond to rather inappreciable amounts of slope. The latter are obtained by expressing the depth of the sea in 10000 metres as a unit and dividing it by the number found in the table. Thus, for instance, if in a 5000 m. deep part of the ocean in 10° N a deep-current is directed at 60° to the North of the parallel, and if a section of the sea is constructed in the direction of the current, it follows from the table that this section should show a bottom slope of $\frac{5000}{10000}$ to 130, that is 1 to 260. In latitudes below 5° a very steep slope would be required to give to the deep-current a direction deviating considerably from the parallel. On the other hand it is seen from the table that in moderate or high latitudes (30° or 40°, say, or more) the current will always take a direction in which the slope of the bottom is comparatively small.

36. In § 28—35 I have tried to give in a simplified form an outline of the theory of 1923 as far as the rotation of deep-currents in homogeneous water is concerned. As was already mentioned, there is still one circumstance which has not been duly considered in this theory. The latter was founded on the principle that the deep-currents neither converge towards nor diverge outwards from any part of the sea; and this principle again depended on the assumption that the acceleration of the water could be neglected. We have already met with a case (§ 24),

where this was not permissible, because the water-transport produced by a deep-current during its first hours of rise was of essential consequence for its further establishment. We meet now with a similar case. When, for instance, a local elevation of the sea-surface has been produced, the deep-current initially, during the first few hours, diverges first in the radial direction and then in spiral paths out from the region, and if the water is sufficiently deep, this outflow may be of as much (or even more) importance as the subsequent and more lasting outflow due to the bottom-current alone. It entirely depends on how long this latter outflow continues.

A recent investigation, of which only a preliminary account has as yet been published (this Journal, Vol. III p. 104, 1928), proved that for the reasons just displayed the theory of 1923 must certainly not be abandoned, but on some points materially modified. For the present I must confine myself to illustrating by an example the direction in which the modification will take place. Consider for the purpose the case of a "corrugated" sea-bottom as represented by Fig. 8. The result will here be modified in two directions. Firstly the amplitudes — i. e. the angles of deviation of the stream-lines from their average direction — will be diminished; and secondly there will be an alteration of phase, so that the upper part of Fig. 8 should be displaced to the right relatively to the lower part. In both cases the magnitude of the alteration will depend on the depth, the velocity of the current, and the breadth of the bottom ridges. The decisive quantity is the quotient d/D'' between the depth of the sea and the lower depth of frictional influence, divided by the time τ in pendulum-days required for the deep-current to cover the distance between two ridges. If $\frac{\pi d}{D\tau}$ is a small fraction, the alteration will be insignificant, but if it is a large number, or only of the order of magnitude 1, the alteration will be considerable. The latter case will probably best correspond to the real conditions in the ocean if the deep-currents are not very slow, and if exception is made for the influence of the largest topographical features.

37. Owing to the circumstances described in the last paragraph the results of the theory of deep-currents are as yet rather uncertain as regards the details. The principal results may however be briefly summed up as follows:

The deep-currents have a tendency, particularly decided in low latitudes, to follow the parallels of latitude.

They have a tendency, particularly in higher latitudes, to follow the main features of the depth contours.

When running over a sea-bottom with a more irregular, broken topography the currents will have a tendency to *contra solem* rotation when running over the deeper regions or in the direction of deepening water; and *vice versa* when running over the shallower parts or in the direction of shallower water. In addition the topography will have the effect of reducing the velocities of the deep-current.

In the same degree as the velocities of the deep-currents are for these or other reasons reduced as compared with the surface-currents, the planetary and topographic rotational effects will be of less consequence, and the deep-currents will be governed by other circumstances, as for example the wind.

In intermediate latitudes the deep-currents will be governed by a compound effect determined by the various circumstances mentioned above.

Convection-currents.

38. The convection-currents present of course a much greater variety of individual problems than the drift-currents. For their investigation the well-known theorem of V. Bjerknes has proved to be an excellent instrument. On the other hand very little has been done as yet in this direction by the method of type problems, but a few results obtained in this way may be worth mentioning.

Since the differences of density are mainly concentrated in the upper water-layers, the problem may be simplified by the assumption of an absolutely homogeneous "deep-water" layer and above it a non-homogeneous "top-layer", which alone is the seat of a field of solenoids. The deep-water will under these assumptions be subject to forces quite similar to those acting on an altogether homogeneous ocean; with the only difference that the friction acting on its upper boundary-surface is not due to the wind but to the motion of the top-layer water. The motion of the deep-water will correspondingly be made up of a bottom-current, a uniform deep-current (the gradient-current), and in the uppermost layer of the deep-water a current due to friction, which I have proposed to denote as the "internal drift-current", and which forms the continuous transition from the deep-current to the currents of the top-layer.

39. As for the distribution of density within the top-layer a very great variety of cases would, from a purely geometrical point of view, be possible. This great variety of alternatives is, however, under certain assumptions materially reduced by a "theorem of the parallel fields of solenoids" due to B. Helland-Hansen and the writer (1923). The

purport of the theorem, which does not claim more than approximate validity, is as follows:

When considering the surfaces of equal density in the various levels along a vertical line their tangent planes will all be situated so as to be parallel to one horizontal line. Furthermore the tangent planes to the isothermal and isohaline surfaces as well as the velocities of the water in the various levels will all be parallel to the very same horizontal line. The velocity of the elementary current will therefore have either one direction or two contrary directions in the various levels.

40. It is important to mention the various assumptions on which the theorem depends; and the outlines of its proof ought to be given as well, so as to enable the reader to form an opinion of the extent of its validity. Firstly it depends on the assumption that the condition of the sea (i. e. the distribution of temperature and salinity etc.) is, at the time, invariable. This implies that the velocity of the water must everywhere be tangential to the isothermal and isohaline surfaces and to the surfaces of equal density, since otherwise these surfaces would be displaced by the current. If furthermore the latter be supposed to be everywhere horizontal, it must consequently be directed along the horizontal tangents to the above-mentioned characteristic surfaces.

Furthermore it is assumed that the velocity of the water is everywhere "normal" and that viscosity and eddy-viscosity have no significant influence — at any rate not as far as the direction of motion is concerned. Now consider two adjacent water-layers of different densities and the surface of equal density separating them. If this surface is sloping, there will according to the theorem of BJERKNES be a relative velocity of sheer of the one water-layer above the other; and on account of the above-mentioned assumptions this relative velocity is directed along the horizontal tangent to the separating surface and is therefore parallel to the absolute velocity of the water.

The absolute velocity and the relative velocity of sheer being thus, in each particular level, parallel to one another, it follows immediately that the absolute velocities in all levels are parallel to one another; and consequently the same will be the case with the horizontal tangents to the above-mentioned boundary-surfaces.

41. A few remarks ought to be added regarding the validity of the theorem. On account of the first assumption it would not hold good during a period when the physical conditions of the sea are being altered, as e. g. during an influx of warm water into a region previously occupied by colder water. The assumption of "normal" velocities implies that the theorem does not hold good in such cases where the stream-lines

are eventually very sharply bent as e. g. off a prominent point of land like the Skaw, say. It is hardly necessary to point out that it is not applicable to the bottom-currents and the pure drift-currents, since viscosity is neglected. In the case of real convection-currents, however, viscosity is not likely to affect considerably the directions of velocity (compare § 43 below) and to vitiate the validity of the theorem, if the thickness of the solenoid-layer is at least of the order of magnitude D, and if exception be made in the case of layers of a pronounced discontinuity.

On the other hand the theorem would be applicable under ordinary circumstances to the great and comparatively steady convection-currents in the open ocean. Certainly, since the motion of the water at some distance from the sea-surface cannot be guaranteed to be absolutely horizontal, the theorem would be quite consistent with the current veering over a small angle from one level to another, particularly if the inclinations of the boundary-surfaces are not comparatively great. But it would be in decided contradiction to a hypothetical field of currents — sometimes met with in older charts but more rarely in modern works — where two surface-currents cross one another after the pattern of an under-bridge as in Fig. 10.

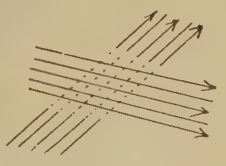

Fig. 10.

Fig. 11 and 12 give an example of a remarkably close approximation to the theorem in question. They represent theoretical stream-lines in the North Atlantic as calculated dynamically by Helland-Hansen from temperatures and salinities. Fig. 11 represents the stream-lines corresponding to the motion of the surface-water relative to the water at 600 metres' depth and Fig. 12 the same relative to the water at 1000 m. It should be added that there is here, within the region of the Gulf-Stream, a considerable difference of velocity between 600 m. and 1000 m., and that therefore the conformity between the two sets of curves implies a corresponding conformity between the stream-lines of the real currents. Similar remarkable illustrations are to be found in a recent paper by Helland-Hansen and Nansen[1]).

42. The problems of convection-currents due to "parallel" fields of solenoids are comparatively easily treatable (1924) by means of linear differential equations, if it is permissible to regard the virtual coefficient of viscosity as a constant; so that it is perhaps not quite impracticable to

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[1]) Bjørn Helland-Hansen and Fridtjof Nansen, The Eastern North Atlantic, Geofys. Publ. IV Nr. 2, Oslo 1926.

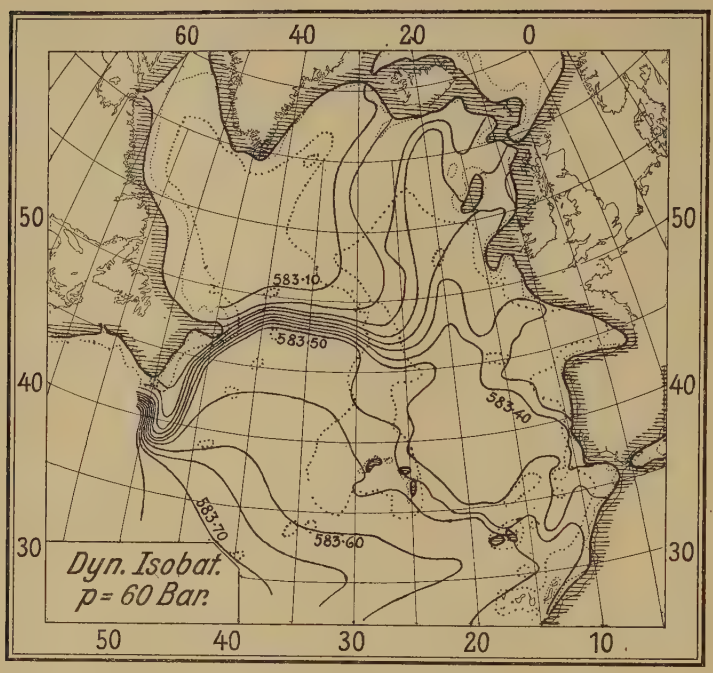
60
40
20
0
50
40
30
583·10
583·50
583·40
583·70
583·60
Dyn. Isobat.
p = 60 Bar.
50
40
30
20
10

Fig. 11.

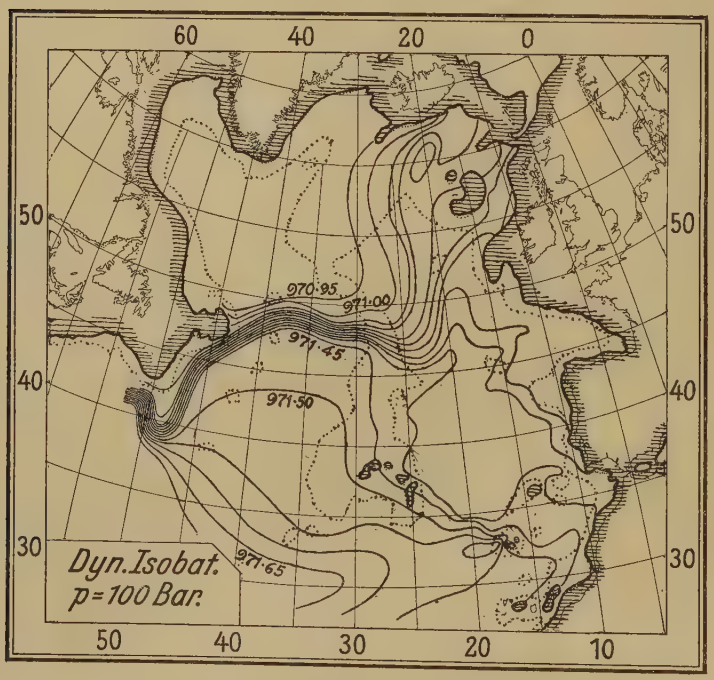
60
40
20
0
50
40
30
970·95
971·00
971·45
971·50
971·65
Dyn. Isobat.
p = 100 Bar.
50
40
30
20
10

Fig. 12.

solve mathematically a series of type-problems answering the indispensable needs of the oceanographer.

This is not the place to report a number of such individual problems — and there are indeed not many of them solved as yet. It may be sufficient to represent graphically the result of a series of 3 type-problems, which are of some interest for a judgment of the degree of accuracy with which the theory of BJERKNES can be expected to reproduce the actual currents. For simplicity it is supposed that in the homogeneous deep water there is no horizontal pressure-gradient and therefore no gradient-current. In the absence of friction the field of solenoids would then in

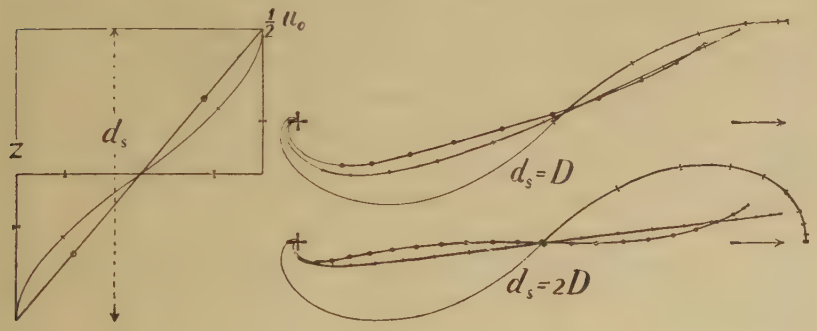

Fig. 13.

the various levels of the top-layer give rise to parallel currents running everywhere at right angles to the direction of the pressure-gradient. By determining for each particular level below the sea-surface the velocity u_0 of this hypothetical current the field of solenoids is completely defined.

In this way three different parallel fields of solenoids are graphically represented by the left-hand diagram in fig. 13. The depths z below the sea-surface are plotted vertically, and the values of $\frac{1}{2} u_0$ are plotted horizontally. The inclined straight line marked by circles o represents a homogeneous field of solenoids, the velocity u_0 increasing uniformly upwards along the vertical; and the dotted line d_s denotes the thickness of the solenoid layer at the bottom of which u_0 is *nil*. The curved line marked by thin strokes represents a field of solenoids according to the equation $u_0 = C\,(1 + \cos \frac{\pi z}{d_s})$. This field is of the same thickness as the previous one, but more concentrated to the middle levels, as if there were in these levels a slight indication of a discontinuity-layer. Finally the broken line indicated by the I-shaped marks represents a

field of solenoids due to an inclined and absolutely sharp discontinuity-layer at the depth $\frac{1}{2} d_s$. The strengths of the fields of solenoids are chosen so as to make the surface-velocity u_0 the same in all three cases.

The upper right hand diagram represents the currents which would be produced, if there were in all levels an eddy-viscosity corresponding to a depth of frictional influence $D = d_s$. The three curves issuing from the Maltese cross represent the currents produced by the three respective fields of solenoids, an arrow drawn from the cross to any point in the curve representing the direction and velocity in a corresponding particular level. The faint part of each curve represents in this way the motion of the homogeneous deep-water (the internal drift-current). The thick part of the curve, which carries the marks representative of the solenoid-layer, shows the motion of the top-layer, and the marks are put in at intervals corresponding to layers of the thickness 0.1 D. For comparison a flying arrow is inserted to the right in the figure; if extended backwards so as to issue from the cross it represents the surface-velocity u_o in absence of friction.

The lower right hand diagram represents in exactly the same way the currents produced by the same fields of solenoids, if the depth of frictional influence is only half as large.

43. It is not necessary to discuss the diagrams in detail. I only wish to call attention to an interesting conclusion, which may apparently be inferred from them, viz. that when calculating by means of the theory of BJERKNES the currents produced by a parallel field of solenoids, the degree of accuracy of the calculated velocities will materially depend upon the thickness of the field of solenoids d_s as compared to the depth of frictional influence D. If d_s is equal to D or larger, the velocities will be correct at least as far as their order of magnitude is concerned, and the directions will be correct to within, say, a point of the compass. If d_s is equal to $2\,D$ or larger, the agreement will be rather good, both when the velocities and when the directions are considered. Exception must be made only in the case of the water-layers which are situated in the neighbourhood of the discontinuity-layer.

So far the circumstances are favourable for the calculation of convection-currents by means of the theory of BJERKNES, in any case if the field of solenoids is comparatively deep and without strongly pronounced discontinuity-layers. In case these conditions are not fulfilled the results might without much difficulty be improved by comparison with the exact solution of a similar type-problem, if a convenient series of such problems has once been prepared.

44. There is one more circumstance which is of importance in connection with the practical application of BJERKNES' theory. This theory gives, as is well known, only the differences of velocity between different levels, e. g. the velocities of the surface-layers relative to the deep-water. In order to calculate the absolute velocities it would be necessary to know accurately the slope of the sea-surface; and since this cannot be observed, our present knowledge depends entirely on theoretical argumentation.

From this point of view it may be of some interest to know that the solenoid-fields in the upper water-layers are not likely to produce indirectly any deep-currents. As a matter of fact it can be shown (1924 and 1927) that a local accumulation of, say, light surface-water in one part of the sea will give rise to a circuit of surface-currents running in the *cum sole* direction, but to no appreciable deep-water circuit. The latter would be produced only in the case when in low latitudes an upper water-layer of considerable depth is running with a considerable velocity-component northwards or southwards. Since no such current is actually known, it can be assumed for the present that deep-currents can only be produced by the winds — of course apart from such very slow currents which are produced by the differences of density within the deep-water layers themselves. In such parts of the sea, where the winds are not likely to produce slope-currents of appreciable velocity, the theory of BJERKNES would therefore presumably result in the approximate calculation of the absolute velocities of the upper water-layers.

List of the author's papers on ocean-currents as far as quoted in this article.

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Figures 2, 3, 8, 11, and 12 taken from Kàrmàn-Levi-Civita, Hydro- u. Aerodynamik.

An Apparatus for Determining the Salinity of Sea Water.

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Introduction.

The "Hydrographical Tables" of MARTIN KNUDSEN give very complete data correlating the density and salinity of sea water, and it was suggested that an accurate means of determining density would provide an indirect means of determining salinity. An apparatus has been designed on this basis, using the temperature of equilibrium of a glass float in a sample of sea water as an indication of the density of the sample[1]). If a glass float, for example a hollow cylindrical glass bulb, is loaded with mercury so as to have a suitable density, it will float in sea water at ordinary temperatures and sink when the temperature is raised sufficiently. At some intermediate temperature the densities of the sample and of the float will be equal and the float will have no tendency either to rise or sink in the liquid. This temperature we will call the equilibrium temperature of the float. If the density of the float at any temperature and its coefficient of cubical expansion are known, then the determination of the equilibrium temperature of the float in any liquid suffices to determine the density of the liquid at that temperature.

[1]) This method of determining density is, of course, by no means a new one. See for example "An Instrument for accurate and rapid Density Measurements on board ship" by A. L. THURAS "Jour. Wash. Acad. Sci". 1917, VII, 605, and "A comparison of the Atomic Weights of Silicon from different sources" by Robinson & Smith "Jour. Chem. Soc." 1926, *129*, 1263.

It was desired that the apparatus should be suitable for determining salinities (measured as the total weight of salt in grammes in 1000 gms. of sea water) over a range of salinity from 33 ‰ to 36 ‰ correct to within ± 0.02 gms. This corresponds to an accuracy of ± 0.000016 gms/ml in density and ± 0.05° C. in determination of equilibrium temperature. It was also desired that the apparatus should be suitable for use on light-ships and vessels of the mercantile marine and to this end it was necessary that only the simplest means of heating should be required, that the apparatus should not be affected by the motion of the ship, that not more than 250 ml of sea-water should be required, and that the apparatus should be simple to use. The apparatus designed with a view to fulfilling these requirements forms the subject of this paper.

Description of Apparatus.

The essential part of the apparatus, as constructed for trial, is shown in Fig. 1. It consists of two vertical glass tubes, A and B, about 2.5 cms. in internal diameter and about 22 cms. long, sealed at their lower ends, open at the top and connected by two horizontal cross-pieces C and D The volume of sea water required is about 150 millilitres which suffices to fill the apparatus to about 1.5 cms. above the top of the connecting limb D. The float E, is placed in the left hand vertical tube which is closed by means of an india-rubber stopper carrying a thermometer. The thermometer scale has a range from 18° C. to 32° C. and is sub-divided into tenths of a degree centigrade, the graduation marks being about 1 mm. apart. The cork closing the limb B has a vertical hole bored centrally through it, and a glass rod F which passes through this hole has a horizontal disc fused at its lower end and serves as a stirrer. The sea water is stirred by raising and lowering F, the diameter of the disc being 2 to 3 mm. less than the internal diameter of the tube B. Two enlargements on the rod F act as stops and limit the motion of the disc to the portion of the tube B lying between the two horizontal connecting tubes C and D.

For preliminary experiments the apparatus was set up as shown in Fig. 2. The apparatus shown in detail in Fig. 1 was held in a retort stand so that it was suspended in a 3000 ml. beaker filled with water, the level of the water in the beaker being well above the level of the liquid surfaces inside the vertical tubes A and B. The water in the beaker was stirred by means of a vertical glass rod bent at its lower end into the form of a hexagon lying in a horizontal plane, and fitting between the walls of the beaker and the apparatus suspended in it.

This arrangement was only intended as a provisional one. A rectangular sheet metal bath having glass windows front and back and provided with a suitable clamp for holding the inner vessel would be more convenient for use at sea. The metal bath could with advantage have a capacity somewhat greater than 3000 ml and so make slow rates of temperature change more easily attainable.

Adjustment of Floats.

It is not convenient on board ship to attain equilibrium temperatures by cooling the samples below room temperature, and on the other hand it is desirable not to have to raise the temperature of the sample more than is necessary. In temperate regions samples of sea water will rarely have a temperature higher than 18° C. A change in salinity from 33 $^0/_{00}$ to 36 $^0/_{00}$ corresponds to about 9° C. change in equilibrium temperature. If the float is adjusted so as to have an equilibrium temperature somewhere between 18° C. and 21° C. in sea water of salinity 33 $^0/_{00}$ then it may be used to determine the density of samples having a salinity 36 $^0/_{00}$ without it being necessary to heat them to a higher temperature than about 30° C. Such a float would be suitable for our purpose. The density of sea water of salinity 33 $^0/_{00}$ is 1.023764 gms/ml at 18° C. and 1.022996 gms/ml at 21° C., so that the float will be convenient if at 18° C. it has any density lying between these values, for this will bring its equilibrium temperature in a sea water of salinity 33 $^0/_{00}$ within the range 18° C. to 21° C. The permissible variation in the density of the float at 18° C. is therefore (1.023764—1.022996) gms/ml i. e., 0.000768 gms/ml. The volume of the float used was about 7 ml. so that the permissible variation in density corresponds to a latitude of about 5 milligrammes in adjusting the mass of the float. This is quite a practicable proposition and no difficulty was experienced in obtaining floats suitably adjusted from a hydrometer manufacturer.

Determination of Equilibrium Temperature.

Starting with the apparatus assembled as shown in Fig. 2, with the water in the beaker and the sample in the inner vessel both at room temperature, the float will be at the surface of the liquid in the vertical tube containing the thermometer. A small quantity of hot water is added to the beaker, both inner and outer vessels are stirred and the behaviour of the float after the effects of stirring have subsided is noted. If the float returns to the surface of the sample more hot water is added to

the outer vessel and the stirring and observation of the float repeated. This is continued until the float is seen to remain at the bottom of the sample. The temperature of the sample will then be a little above the equilibrium temperature and the following operations should be carried out repeatedly in the order enumerated:—

1) The water in the outer vessel is stirred.
2) The sample in the inner vessel is stirred.
3) When the motion imparted to the float by the stirring has died out[1]) the float is watched carefully to see whether it rises or sinks.
4) Immediately it has been decided whether the float tends to rise or to sink, the thermometer is read to the nearest 0.01° C.
5) The time is noted as soon as the thermometer reading has been recorded. This is not essential but is useful for indicating the rate at which the temperature is changing.

The above series of observations is repeated until the temperature falls below the equilibrium temperature.

A set of readings with rising temperature may then be obtained by adding hot water to the outer vessel in small quantities at a time so that the temperature slowly rises through the equilibrium temperature. When passing through the equilibrium temperature the rate of change of temperature should not be greater than 0.1° C. per minute.

It is convenient to record the observations as follows:—

						A			B	
Behaviour of Float . .	S	S	S	S	S	S	R	R	R	S
Temperature °C.	21.22	21.19	21.17	21.12	21.10	21.06	21.02	20.99	20.99	21.03
Time from start (Min.)	0	$2\frac{1}{4}$	$3\frac{3}{4}$	$5\frac{1}{4}$	$6\frac{3}{4}$	$8\frac{3}{4}$	$10\frac{1}{4}$	12	$15\frac{1}{3}$	$17\frac{1}{4}$

			C			D	
Behaviour of Float . .	S	S	S	E	R	R	S
Temperature °C.	21.09	21.10	21.08	21.02	20.99	20.99	21.04
Time from start (Min.)	$18\frac{3}{4}$	23	$24\frac{1}{3}$	$26\frac{1}{2}$	$27\frac{3}{4}$	$30\frac{1}{4}$	$32\frac{1}{4}$

S = Float sinks. R = Float rises. E = Float in equilibrium.

The means of the temperatures enclosed in the rectangles marked A, B, C and D, which include temperatures in the immediate neighbourhood of the equilibrium temperature, when the temperature was falling

[1]) The stirrer in the inner vessel can be used to control the motion of the float. By gently moving the stirrer up and down, as required, the float may be manipulated so as to come steadily to a position about midway between the bottom of the inner vessel and the surface of the sample. After a little practice one is soon able to discriminate between a motion of the float imparted to it by stirring and motion in accordance with the difference in density between the float and the surrounding liquid.

in A and C and rising in B and D, are 21.04° C., 21.01° C., 21.03° C. and 21.01_5° C. respectively. The mean of all four values viz., 21.02° C. is taken as the equilibrium temperature.

One passage of the temperature through the equilibrium temperature suffices to determine the latter but it is preferable to obtain two values one with falling and one with rising temperatures to serve as a check on the consistency of the results obtained.

Results obtained with the Apparatus.

1) Determination of Equilibrium Temperatures at the National Physical Laboratory.

The first thing to be ascertained was whether the apparatus was suitable for locating the equilibrium temperature in any sample to a sufficient degree of accuracy. Three observers, normally occupied in testing volumetric glassware, each determined the equilibrium temperature of a float in a salt solution taking two determinations with rising and two with falling temperatures. The mean of each observer's determinations differed from the grand mean by not more than 0.02_5° C. not only in the observations just mentioned but also in two other similar sets of observations. Further no individual observation in any one set of observations differed from the final mean of the set by more than 0.05°C. This applied to a total of thirty eight observations in all, each determination by any one observer with rising or falling temperature being counted as an individual observation. The results quoted were the first observations carried out with the apparatus by the observers concerned, so that the degree of accuracy required was achieved without any lengthy experience in the use of the apparatus.

The observations were all taken in the same sample. The mean of the results obtained in the first series including one set of determinations by each observer was 28.11° C., in the second series 28.11° C. and in the third series 28.13° C. The observations were carried out on two successive days and twenty six hours elapsed between the first and last observation the sample remaining in the apparatus throughout this period. The small change in equilibrium temperature over this long period shows that there is no fear of any change in salinity during the course of an ordinary observation of equilibrium temperature.

These preliminary results indicated that the apparatus might be expected to function satisfactorily and the Government Chemist, Sir Robert Robertson, kindly arranged for the apparatus to be tried at the Government Laboratory in conjunction with their titrations of samples of sea water.

2) Results obtained at the Government Laboratory.

At the Government Laboratory the equilibrium temperature was determined in a series of nine samples of sea water of which the salinity was determined by titration. The salinities ranged from 33.2 $^0/_{00}$ to 35.6 $^0/_{00}$ and from the results obtained a graph was drawn correlating salinity and equilibrium temperature. The salinity of seventeen more samples was determined by observing the equilibrium temperature of the float in each sample and obtaining the salinity from the graph constructed on the basis of the first nine samples. The salinity of each sample was also determined by titration. Reporting on the results obtained Sir Robert Robertson wrote:—

"Of the seventeen samples examined one gave a result 0.04 below the mean titration value, one was 0.03 above and another 0.025 below. The others either agreed exactly in the second decimal place or differed by not more than 0.02 from the value obtained by titration.

The apparatus has thus been found to work well with samples of salinity 33.0 to 35.5 $^0/_{00}$.

As far as can be judged from Laboratory experiments, the apparatus appears to be suitable for the purpose for which it was designed, and it is capable of giving results of the accuracy indicated above in the hands of a careful worker."

3) Results obtained on Cruise XI (1925) on board the "George Bligh".

Dr. Russell kindly arranged for observations to be made with the apparatus at sea on the Ministry of Agriculture & Fisheries research vessel "George Bligh". A beaker was used for the outer bath as in the experiments on shore, but, as stated previously, this arrangement is only a provisional one. A float, Nr. 3, was used for which the National Physical Laboratory furnished the data given in Table I.

The table was prepared by determining the equilibrium temperature of the float in a series of salt solutions in which the equilibrium temperature of a "standard float" was also determined. The "standard float" was one for which equilibrium temperatures had been determined at the Government Laboratory in samples of sea water of known salinity determined by titration.

Salinities were determined on board ship by observing the equilibrium temperature and obtaining the salinity from the above table. Duplicate samples were preserved in sampling bottles for subsequent analysis at the Government Laboratory. Salinities were determined by

Table I.

The Table gives the salinities (i. e., total weight of salt in grammes in 1000 grammes of sea water) corresponding to the tabulated equilibrium temperatures.

° C.	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
20	32.81	32.84	32.87	32.90	32.93	32.96	32.99	33.02	33.05	33.08
21	33.11	33.14	33.17	33.21	33.24	33.27	33.30	33.33	33.36	33.40
22	33.43	33.46	33.49	33.53	33.56	33.59	33.63	33.66	33.69	33.73
23	33.76	33.79	33.83	33.86	33.90	33.93	33.97	34.00	34.04	34.07
24	34.11	34.14	34.18	34.21	34.25	34.28	34.32	34.36	34.39	34.43
25	34.47	34.50	34.54	34.58	34.62	34.65	34.69	34.73	34.77	34.80
26	34.84	34.88	34.92	34.96	35.00	35.04	35.08	35.11	35.15	35.19
27	35.23	35.27	35.31	35.35	35.39	35.43	35.47	35.52	35.56	35.60
28	35.64	35.68	35.72	35.76	35.80	35.85	35.89	35.93	35.97	36.02
29	36.06	36.10	36.14	36.19	36.23	36.27	36.32	36.36	36.41	36.45

means of the apparatus by three observers (Messrs. J. N. Carruthers, J. R. Lumby and V. Stott) during a cruise from Lowestoft to Sylt thence to Bridlington and back from there to Lowestoft. The results obtained at sea are given in Table II.

Table II.

Station	Observers			Mean
	A	B	C	
A	33.95	33.95	33.96	33.95
6	34.25	34.26	34.25	34.25
7	32.89	32.87	32.88	32.89
	..	..	32.90	..
13	34.89	*34.96*	*34.88*	34.91
14	34.94	34.92	34.96	34.94
19	*34.26*	34.21	34.21	34.23
	34.24	..	34.23	..
B (a)	33.92	33.90	33.90	33.91
	33.91	..	33.91	..
B (b)	33.89	33.89	33.87	33.88
C (a)	33.87	..	33.86	33.86
C (b)	33.86	33.85	..	33.85

Only the three observations given in italics out of a total of thirty three observations differ from the mean value for the sample by more than 0.02 $^{0}/_{00}$. The results of the determination of the salinities of duplicates

of the above samples at the Government Laboratory are given in Table III in which the mean results from Table II are also given for comparison. No duplicate sample was taken for analysis at station A.

Table III.

Station	Salinity from equilibrium temperature of float (1)	Salinity by Titration (2)	Difference (1) — (2)
6	34.25	34.24	+ 0.01
7	32.89	32.82	+ 0.07
13	34.91	34.86	+ 0.05
14	34.94	34.86	+ 0.08
19	34.23	34.15	+ 0.08
B (a)	33.91	33.87	+ 0.04
B (b)	33.88		+ 0.01
C (a)	33.86	33.84	+ 0.02
C (b)	33.85		+ 0.01

If the values of the salinity obtained by each method are correct within $\pm$ 0.02 $^0/_{00}$ then the differences in the last column should not exceed $\pm$ 0.04 $^0/_{00}$ and in general should be less than this. Four of the differences exceed 0.04 $^0/_{00}$ so that one would not feel safe in substituting determinations by the new apparatus for the established titration method without further investigation. All the differences in the last column are positive which suggests a constant error the elimination of which would bring the two sets of results into closer agreement. It was not possible however to assign a definite reason for the presence of any constant error.

For the determinations marked B (b) and C (b) the sample was placed in a sample bottle of the usual type having an air tight stopper. The bottle was placed in warm water, temperature 30° C., and shaken to release air bubbles from the sea water. The sample was then transferred to the apparatus for determination of the equilibrium temperature. This was done because in previous determinations trouble had been experienced through the formation of air bubbles on the float. This necessitated interrupting the observations to remove the bubbles by withdrawing the float from the sample. No trouble with bubbles was experienced when the samples were first warmed as described and the agreement between the results B (a) and B (b) and between C (a) and C (b) indicates that the method employed for preliminary heating of

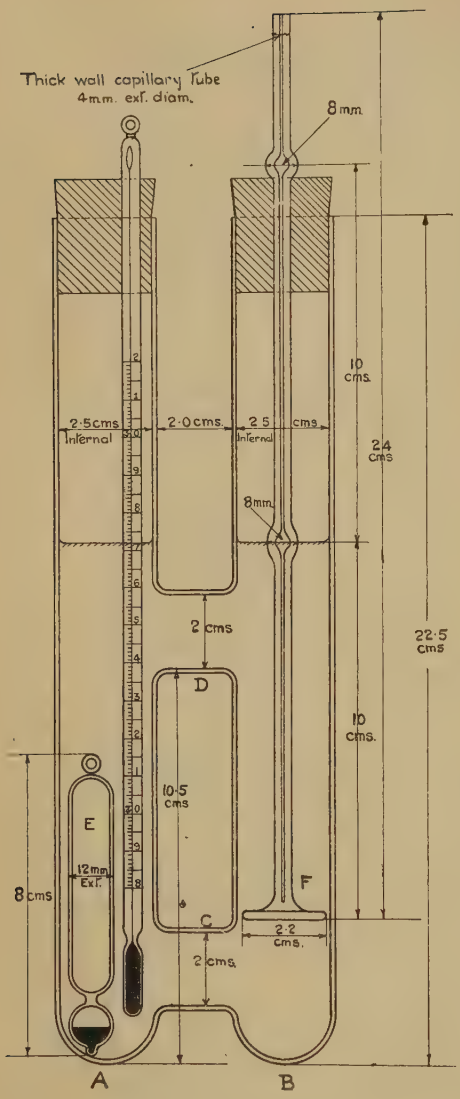

Fig. 1.

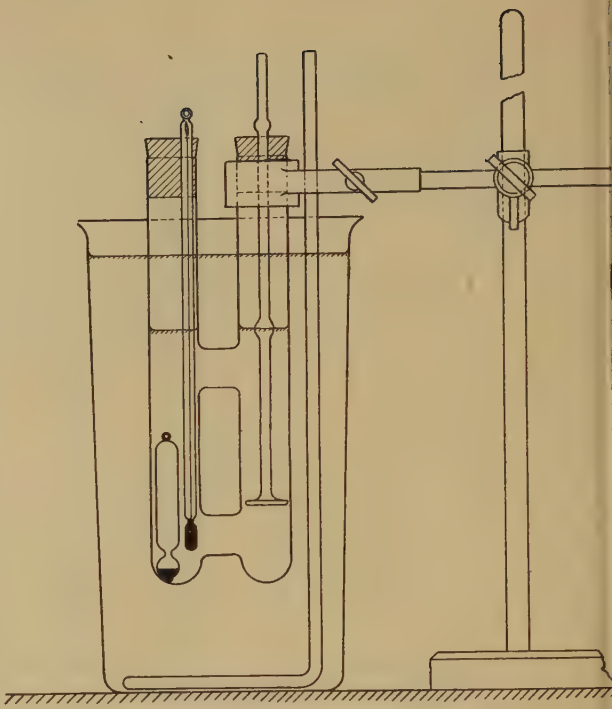

Fig. 2.

the sample does not change the salinity as samples B (a) and C (a) were identical with B (b) and C (b) the only difference in procedure being that the samples B (a) and C (a) were not warmed before the determination of the equilibrium temperature. It is, of course, desirable for other reasons to keep the float quite clean, e. g. by washing in a soap solution and then thoroughly rinsing before use, and this also helps to keep the float free from bubbles.

The apparatus shown in Fig. 1 was used for samples A, 6, 7 and 13 but for the remaining samples an alternative form of apparatus shown in Fig. 3 was used. The construction of this apparatus is clear from the diagram and the method of use was the same as with the original form. It will be seen that equally good results were obtained with both forms of apparatus. The float can be more easily controlled in the original form of apparatus and it is a slight advantage to have the stirrer and

thermometer in separate corks as in Fig. 1 rather than to have both in the same cork which has also to carry the central tube as shown in Fig. 3. There is less lag between the temperature of the outer bath and of the sample with the original form of apparatus than with the concentric form.

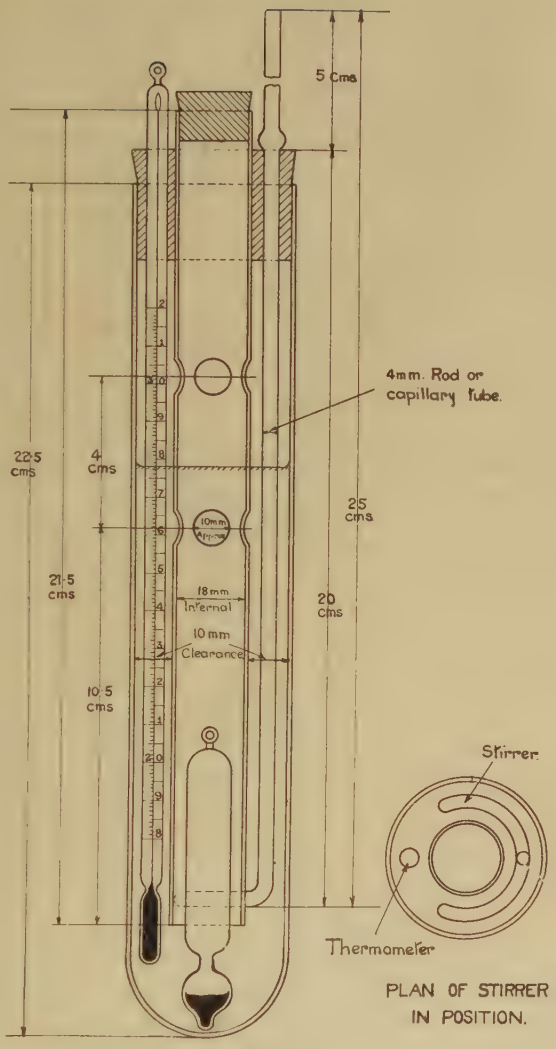

Fig. 3.

4) Results obtained on Cruise F (1927) on board the "George Bligh".

Observations were made on board the "George Bligh" by the same three observers as on the previous cruise, on a run from Lowestoft to the Varne Light Vessel and during a period of about two days whilst the ship was at anchor near the Varne for the purpose of current measurements.

The results obtained are given in Table IV the salinities being obtained from the equilibrium temperatures by means of Table I.

Only the three values in italics out of a total of twenty observations differ from the mean value by more than 0.02 $^{0}/_{00}$, and none of the values in the second column differ by more than 0.02 $^{0}/_{00}$ from the corresponding values in the third column of the table.

The salinities of duplicates of all the samples were subsequently determined by titration at the Government Laboratory. The results together with the mean values from Table IV are given in Table V.

Table IV.

Sample Number	Observers			Mean
	A	B	C	
31	33.54	33.56	..	33.55
32	34.19	34.19	*34.23*	34.20
33	35.02	35.01	..	35.01
34	*35.00*	..	*35.08*	35.04
35	34.86	34.87	..	34.86
36	34.90	34.88	34.87	34.88
37	34.91	34.90	34.89	34.90
38	34.84	34.84	34.87	34.85

Table V.

Sample Number	Salinity from equilibrium temperature of float (1)	Salinity by Titration (2)	Difference (1) — (2)
31	33.55	33.51	+ 0.04
32	34.20	34.23	— 0.03
33	35.01	35.00	+ 0.01
34	35.04	34.99	+ 0.05
35	34.86	35.00	— 0.14
36	34.88	34.83	+ 0.05
37	34.90	34.98	— 0.08
38	34.85	34.85	0.00

Two of the differences in the last column i. e., those for samples Nos. 35 and 37 are considerably in excess of the value 0.04 $^0/_{00}$ corresponding to accuracy within $\pm$ 0.02 $^0/_{00}$ in both methods. Both positive and negative differences occur, as compared with only positive differences in the results of the earlier cruise (Table III).

Conclusion.

The outstanding advantage of the float method is that only one observation, and that a simple determination of temperature, is necessary to obtain the salinity of a sample. The equilibrium of the float is very sensitive to small changes in density and given a slowly changing temperature in the neighbourhood of the equilibrium temperature this can be determined with considerable precision. Satisfactory temperature control

can be obtained by adding hot or cold water to the outer bath as may be necessary, and no thermostatic control is required.

The agreement between results obtained with the apparatus and salinities determined by titration was quite satisfactory when the comparison was made at the Government Laboratory where the same sample could be used for both methods and both determinations could be made within a short space of time.

The agreement between results obtained with the apparatus on board ship and the salinities determined some weeks later on duplicate samples by titration at the Government Laboratory was not so satisfactory. Notwithstanding this it was thought that a description of the apparatus and an account of the experiments carried out might prove of interest and so this note has been written.

I am much indebted to Sir Robert Robertson for kindly having experiments with the apparatus conducted at the Government Laboratory, to Dr. E. S. Russell for arranging for the observations on board the "George Bligh" and to Mr. J. R. Lumby for his interest and help in this part of the work.

Modification of the Surface Sampler with a view to the Improvement of Temperature Observation.

By

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In the earlier paper (1) describing the Surface Sampler, I mentioned that the objects for which the apparatus was designed were two-fold, namely, to make easier the actual collection of samples from the sea surface, and to procure a better sample to be retained for salinity analysis, when the collection is made from commercial ships. Furthermore, certain modifications of the instrument were outlined which, it was considered, might lead to an increased reliability of the temperature observations. These ideas are put into practical effect in the modified Surface Sampler now to be described.

The difficulties attending the observation of sea surface temperature from ordinary sea-going ships are well displayed in the Instructions to Marine Meteorological Observers (2) from which the following quotation is made.

"Experience has shown that numerous difficulties exist in the making of accurate water temperature observations. In the first place it is not an easy matter to dip up from the sea, from the deck of a moving vessel, a sufficient quantity of water so that the influences which immediately begin to operate to change its temperature shall not make too great headway before the thermometric reading can be made. Often the bucket used can be only partially filled, even by the most skillful handling. Some vertical stiffening of the ordinary canvas bucket and an extra middle ring to prevent collapse on entering the water are desirable. Sometimes a small quantity of water of a different temperature is in the bucket when the final dip is made. In the case of canvas buckets evapora-

tion from the surface of the fabric operates to change the temperature of the content. Sometimes the temperature of the water drawn up has been affected by the discharge through ejection pipes.

If the temperature of the wet bulb is different from that of the water the latter is affected as soon as the water is dipped from the sea. By the time a bucket can be drawn upward through a distance of from 30 to 60 or more feet, landed upon the deck, and the thermometer immersed in the water for a suitable period of time the temperature of the water will have undergone a definite change – in the direction of that shown by the wet bulb.

Instructions that have heretofore been given for making water temperature observations provide that the water shall be drawn in a canvas bucket from a point forward of the ejection pipes and that the bulb of the thermometer shall be immersed for three minutes and read with the bulb still in the water in the bucket. At times, however, there is a rapid cooling of the water in the bucket due to strong cold winds and on such occasions a shorter period of immersion is desirable. With a reasonably active stirring the thermometer will indicate the water temperature in one minute. Experience shows that readings should be made only in buckets not less than two-thirds full and that the bucket should be protected from the sun and wind."

A thorough study of the conditions governing the observation of surface temperature at sea, and the accuracy with which such observations are commonly made has been undertaken by Dr. Brooks (3), in which he classifies the chief sources of error which obtain when the observation is made on a sample of water withdrawn from the sea, e. g. by means of a bucket. They are given as follows:—

"Sources of error in the bucket method. — In the course of an observation with any type of bucket there are numerous influences tending to make the final record depart from the actual surface temperature: (1) The bucket is not likely to have the same initial temperature as the sea surface; (2) the water sample being hauled up is usually cooled by evaporation; (3) the thermometer inserted is seldom at the same temperature as the water in the bucket; and (4) while it is resting in the bucket further cooling, or perhaps heating, of the water may take place; (5) when the thermometer is read it may not have reached the temperature of the water in which it is immersed; and (6) if it is withdrawn, to be read more easily, the temperature of the very small sample in the reservoir may change before the temperature is observed; furthermore (7) after the markings and numbers have become indistinct errors of reading creep in, and it is easy to see the same temperature as at the

last reading, (8) the thermometer itself may be inaccurate, and (9) there is a slight chance that the quartermaster may forget what the reading was by the time he gets to the log book, and simply repeat the preceding figure. Of course, many of these sources of error are usually negligible, but the total effect is not infrequently a departure of several degrees Fahrenheit from what appears to be the true surface temperature."

Though Dr. Brooks concludes his study by recommending the use of thermographs installed in the condenser intake pipes in preference to bucket methods, the attempt to improve the "bucket" method has been persevered with, because in our organisation at least, there are practical difficulties in the way of installing thermographs; for example, on many routes the individual ships from which observations are obtained are frequently changed and it is easier and less expensive to transfer a Surface Sampler from one ship to another than it is to transfer a thermograph. Moreover, though observations at intake depth may on the average be comparable with surface temperatures in the open ocean, experience with the water bottle in marginal seas, in particular the North Sea, teaches that observations at 0 metres not infrequently differ from those at 10 metres by more than 1° C. Thus, if it is possible to obtain an observation from what is commonly called the "surface" and at the same time to reduce the errors attending such an observation — at least to such an extent that the desired accuracy is ensured — one has the satisfaction of knowing that the observations do in fact refer to the same depth from whatever ship they may have come, whereas the depths of condenser intakes naturally vary a good deal.

In the main the new instrument (see Figure 1) is similar to the old, except that it is somewhat larger (weighing about 11 kilos assembled and full of water), the thermometer is included in the apparatus, and an insulating cylinder of celluloid is fitted. The eyebolt J[1]) and the preventer wire K have been discarded for general use.

A brass tube (1) screwed to the base of the apparatus contains the thermometer (2), the upper and lower ends of which are held fast in contrivances resembling packing glands. The upper gland (3) is secured to the brass tube by a bayonet joint (4) and spring (5); the lower gland (6) acts as a guide for the bulb end of the thermometer and in conjunction with a set screw (7) placed near the top of the brass tube, prevents the thermometer from being totally withdrawn from the tube. The glands themselves consist of two parts, which when screwed one into the other compress a rubber washer (8) on to the thermometer.

[1]) The lettering in Figure 1 is the same as in Figure 1 of the earlier paper. The numerals indicate the new parts.

The celluloid insulating cylinder (9) is held away from the outer wall of the apparatus by ebonite distance pieces (10), so that the sample is insulated mainly by a water jacket. An ebonite block (11) is fitted on to the base plate to complete the insulation.

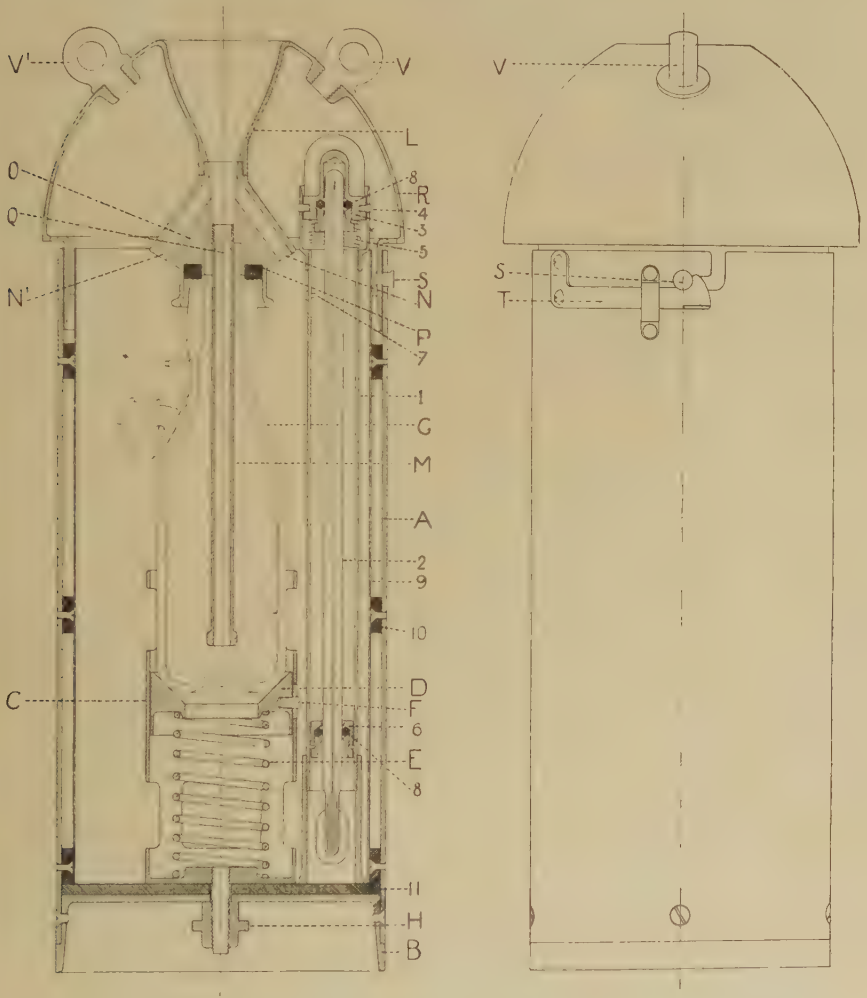

Fig. 1. The Modified Surface Sampler. The lettering is the same as in Fig. 1 of the earlier paper (J. du C. II. 3. 1927, p. 333). The numerals refer to the added parts of the design.

With the modified Surface Sampler the sources of error detailed by Dr. Brooks are guarded against in the following ways:—

The first point is that the bucket has not always the same initial temperature as the sea surface. The Surface Sampler is towed in the

Fig. 2. Comparison of the rates at which the temperature of the sample changes in the several types of apparatus, for differing degrees of difference between wet-bulb and water temperature.

Curve A refers to Sampler with plain brass cylinder.
— B — - — coated internally with cellulose paint.
— C — - — with celluloid cylinder fitted tightly into brass cylinder.
— D — - Modified Surface Sampler.

sea for five minutes or longer, so that it has ample time to acquire the temperature of the water through which it is moving. Its initial temperature therefore has no effect on the final sample. Moreover, a full sample is always obtained.

The second point concerns the cooling of the sample (or warming, if the air is warmer than the water) while being hauled. In the modified Surface Sampler the sample is insulated by the celluloid lining and a water jacket. From Figure 2 (Curve *D*) it can be seen that, with an excess of 15° C. of the water temperature above the wet-bulb temperature, the average rate of change of temperature in the sample (over the first five minutes) was estimated to be less than — 0.1° C. per minute. With an excess of 5° C., the rate would be about — 0.02° C. per minute, so that in such circumstances an interval of 4 to 5 minutes could elapse after the apparatus left the sea before the temperature of the sample altered by 0.1° C.

Before the design was finally adopted, experiments were made to determine a suitable method of insulation. I stated in the earlier paper that lagging the outside of the cylinder with sheet rubber (which, incidentally, might have served to protect the apparatus to some extent from damage caused by knocking against the ship's side) proved of no advantage.

Coating the inside of the brass cylinder with cellulose paint was found to be equally ineffective. A celluloid cylinder of $^1/_{16}$" material fitted tightly inside the brass cylinder of an old type instrument produced an appreciable improvement. As there was insufficient room to include a thermometer as a fixture in the apparatus, the diameter of the brass cylinder and thus the size of the whole instrument were increased, to provide room for the inclusion of a thermometer, and for a water jacket between the celluloid cylinder and the outer brass wall. This arrangement, namely, the provision of a water jacket in addition to the celluloid cylinder, together with the increased bulk of the sample obtained, is again a further improvement.

Figure 2 illustrates this progressive improvement. It shows the rates at which the temperatures of the samples would change under varying conditions of difference between wet-bulb and water temperature, in the several types of apparatus.

To obtain these comparisons, experiments were made on shore in the manner described in the previous paper for series *B* and *C*. The instruments were immersed in a tank of water (of which the temperature was varied as necessary), withdrawn after not less than 10 minutes and placed on a ledge before an open window. Successive readings of the temperature of the water sample were then made; the values for the rates of change of temperature are average rates over about the first 5 minutes after withdrawal from the tank. Points are plotted on the graph (Figure 2) with these values as ordinates and the corresponding differences between

wet-bulb and water temperature as abscissae. To these points straight lines are fitted ($y = a + bx$). A comparison of the gradients of these lines ($\frac{dy}{dx} = b$, see table below) brings out the three following facts. Firstly, an increase in the excess of water temperature over wet-bulb temperature has about the same effect on the rate of change of temperature of a sample in the plain brass cylinder (curve *A*) as on the rate of a sample in the brass cylinder coated internally with cellulose paint (curve *B*). Secondly, this effect is decreased to about two thirds of its original amount, when a celluloid cylinder is fitted tightly inside the brass cylinder (curve *C*). And finally, with the modified instrument (curve *D*), the effect is decreased to a quarter, as compared with the plain brass cylinder.

For curve	*A*,	$b = -0.023$
— —	*B*,	$b = -0.022$
— —	*C*,	$b = -0.016$
— —	*D*,	$b = -0.006$

Thus adequate precaution is made against alteration of the temperature of the sample while hauling, provided that the process of hauling is not unduly prolonged.

Returning to the points enumerated by Dr. Brooks we may take Nos. 3, 4, 5 and 6 together. He states that in the ordinary "bucket" method errors may spring from the insertion of a thermometer not at the same temperature as the sample, from alterations of the temperature of the sample while waiting for the thermometer to acquire that temperature, from the thermometer being read before reaching the temperature of the sample and, finally, from the thermometer being withdrawn from the sample for reading. In the modified Surface Sampler none of these sources of error are present; for since the thermometer is a part of the apparatus, it has always the same temperature as the sample and there is therefore no necessity to wait before reading the thermometer, when the sample has been brought inboard and the head of the apparatus removed. For the same reason it is impossible to read the thermometer before it has acquired the temperature of the sample and, provided the set screw (7. Figure 1) is in position, the bulb of the thermometer cannot be withdrawn from the sample.

Points 7, 8 and 9 deal with errors due to inaccurate reading, to inaccurate thermometers, and to forgetfulness on the part of the Observer. These matters are not guarded against, except in so far as it is possible to promote the interest of Observers in their work by maintaining liaison

with them and to provide for periodic examination and recalibration of the thermometers in use.

There is, of course, always present a far greater measure of the personal element in "bucket" methods than in those where mechanical registration apparatus such as a thermograph is employed. For this reason, in spite of the fact that cooling of the sample while hauling has been guarded against to some extent, this precaution would be unavailing against what could only be termed carelessness and lack of interest. Nevertheless, observations can be obtained under the ordinary routine of a sea-going ship which may be relied upon to a much greater extent than can those obtained by the old methods employing canvas buckets and the like, the fulfilment of the requirements of which cannot reasonably be expected in such circumstances.

To effect this, full consideration must first be given to the conditions under which the work is carried on. Secondly, instruments must be provided which make it practicable for observations to be made under these conditions to the desired degree of accuracy. This latter criterion, it is claimed, is met by the modified Surface Sampler.

It is possible to form an estimate of the reliability of observations made with the Surface Sampler by using Dr. Brooks evaluation of the errors from canvas bucket observations[1]). He finds that, on the average, the quartermasters observations were 0.5° C. (1° F.) below sea temperature. The initial coolness of the bucket seems to account for 0.1° C., cooling while hauling accounts for 0.15° C., cooling while waiting to take a reading for 0.1° C., and "cooling by or of the thermometer, the average error in reading and from inexactness in time of observation" account for the remaining 0.15° C.

With the Surface Sampler the error due to initial coolness of the bucket does not arise. As for the cooling while hauling, the most usual depression of the sling wet-bulb below sea-temperature seems to have been about 8° C, for which depression the rate of change of temperature of the sample would be — 0.04° C. per minute (see Figure 2). If the error which arises when hauling the Surface Sampler is taken to be the same as the combined errors due to cooling when a canvas bucket is hauled and time allowed for the thermometer to settle down, namely, 0.25° C., then 6 minutes could elapse while the Surface Sampler is hauled, its head removed and the thermometer read. I found that the rate of change of temperature of the sample for the canvas bucket with a depression of the wet-bulb $6^1/_2$° C. below water temperature (see previous paper,

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[1]) loc. cit. p. 247.

p. 337, Table 1, columns 4, 7 and 12, series C) was — 0.11° C. to — 0.12° C. per minute. Since the combined error due to cooling of the canvas bucket while being hauled and while the thermometer is being read, is 0.25° C. for a difference (we have assumed) of 8° C. between sling wet-bulb and water temperature, it follows that the canvas bucket was brought inboard, the thermometer immersed and read in not longer than 2 minutes.

The time required to haul the Surface Sampler and to read the thermometer can certainly be no longer (and is probably shorter, in consideration of the fact that there is no necessity to wait for the thermometer to reach the temperature of the sample) than the time required to haul a canvas bucket and obtain a temperature observation.

If 2 minutes is allowed, therefore, for hauling the Surface Sampler and reading the thermometer, the average error due to cooling during this time (2 minutes) would be 0.08° C. (say 0.1° C.), under the same conditions as for an average error with the canvas bucket of 0.25° C.

Errors from cooling by or of the thermometer do not arise, and the average error due to inaccurate reading of the thermometer and inexactness in noting the time of observation may be put at 0.1° C., the same as for the canvas bucket.

The total average error with the Surface Sampler, estimated in this way, is not more than 0.2° C., which is to be compared with an average error of 0.5° C. for the canvas bucket. This comparison is further displayed in the following table:—

Average Error due to:—	Surface Sampler	Canvas Bucket
Initial difference of temperature between apparatus and sea	0° C.	0.1° C.
Cooling while hauling	0.1	0.15
— while obtaining observations		0.1
— by or of thermometer	0	0.05
Inaccuracy in reading	0.05	0.05
Inexactness in time of observation	0.05	0.05
Total...	0.2	0.5

Adaptation for use from Light Ships.

Even when used from ships which steam relatively slowly, (e. g. 8 knots) the Surface Sampler when towed remains in the water surface. At the English light vessels, however, from which routine observations are made, the tidal stream is far from reaching any such speed; in order to make the use of the Surface Sampler possible from these ships, floats

have been provided under which the Sampler is slung (Figure 3) the only addition required to the Sampler being an eyebolt (*A*) screwed into the base. The float (*B*) is constructed in cylindrical form of tinned iron. The diameter of the cross section of the cylinder is 20.3 cms. and the height 38 cms. The weight is $1^3/_4$ kilo. It is fitted with a drain screw (*C*)

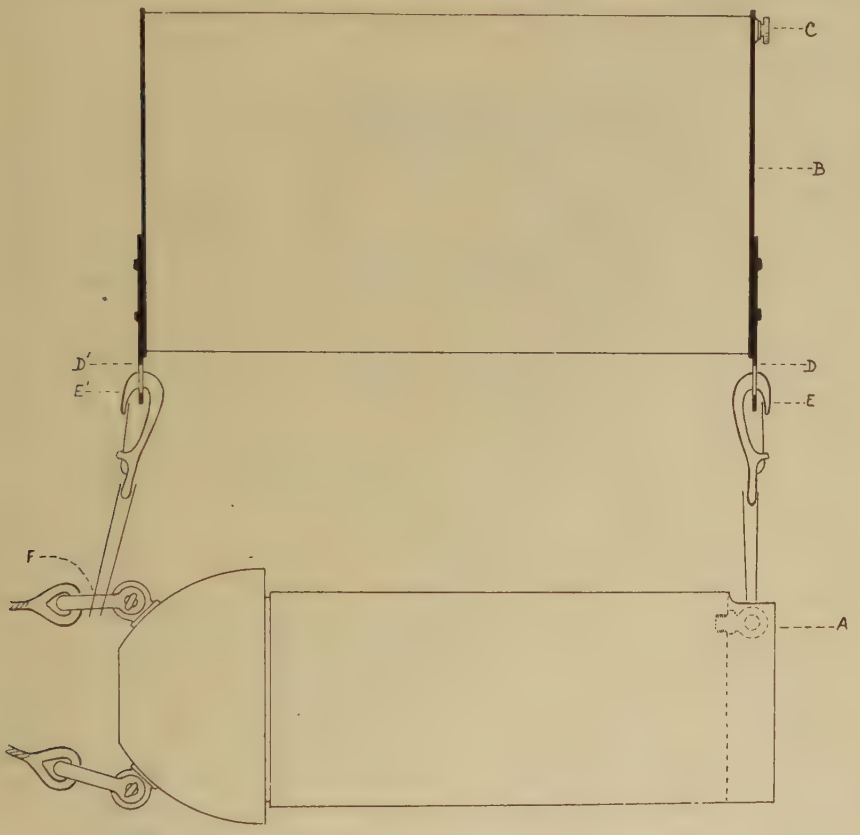

Fig. 3. Method of towing when used from moored Light Vessels.

and two projections (*D*, *D'*) on to which two spring hooks (*E*, *E'*) can be attached. These hooks are lashed respectively to one of the shackles (*F*) secured to an eyebolt in the head of the Sampler, and to the eyebolt specially provided in the base of the Sampler. The gear is worked in the same way as from other ships, except that it is left overboard for a longer period in order to give time for the slower flow of water to effect an efficient washing of the bottle in which the salinity sample is to be stored. The time recommended in these circumstances is half an hour to an hour.

It is to be noted that the sample in this case comes from some 15 to 30 cms. below the surface.

In conclusion, I again have pleasure in acknowledging my indebtedness to Mr. H. J. Garrood for his advice and help in the design, and to Messrs. Elliott and Garrood, Beccles for the drawing of the apparatus from which Figure 1 was prepared.

References.

(1) J. R. Lumby. Journal du Conseil. II. 3. 1927. pp. 332—342.

(2) U. S. Department of Agriculture Weather Bureau. Washington D. C. Circular M. 4th Edition. Jan. 1925. p. 15.

(3) C. F. Brooks. U. S. Department of Agriculture, Weather Bureau. Monthly Weather Review. LIV. 6. Washington 1926. pp. 241—254. (See review on p. 385 of this number.)

Apparatus for quantitative Measurements of Plankton *in situ*.

By

Vilhelm Irgens Pettersson.

This new method for the quantitative determination of the plankton, namely the pumping method *in situ*, has been treated in a previous paper by the author[1]).

In the above mentioned paper there will be found a description of the original type of planktoncatcher with descending weight, constructed in 1925, together with an exposition of its working principle and other details, into which it will be superfluous to enter again. In the following we propose to consider:—

a) A revised model of the same type for deep sea investigations which has been acquired for use on board the m/s "Carnegie" of the Carnegie Institution, Washington, and the s/s "Dana" of the Carlsberg Fond, Copenhagen, during their cruises in the Atlantic and the Pacific Oceans.

b) An apparatus for depths down to some 200 meters only, the motor of which is on board the ship, the power being conveyed by means of the suspending wire down to where the apparatus is supposed to circulate the water through the nets. In 1926 this instrument was ordered to be constructed according to the author's designs by the International Council on the recommendation of the Chairman of the Plankton Committee, Professor Ostenfeld, Copenhagen. On testing its efficiency

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[1]) Svenska Hydrografisk Biologiska Kommissionens Skrifter. Ny serie: Hydrografi II. Nr. 2, Vilhelm I. Pettersson: A new Planktoncatcher.

[2]) The President of the Scripps Institution of Oceanography Professor Dr. Wayland Vaughan, who from the first has been a promoter of sampling plankton *in situ* has also in use a catcher of this type for quantitative investigations along the Pacific coast of U. S. A.

on board the m/s "Johan Hjort" in Lofoten waters in the spring of 1927, it became evident, however, that the ready-made current recorder by its construction for a very high pressure prevented the water from circulating freely enough, wherefore the records constantly remained too low. The Council then in Stockholm 1927 on the recommendation of its Plankton Committee resolved to have a recorder specially constructed and fitted into the apparatus. This having been carried through in the spring of 1928, the completed instrument was demonstrated to the members and experts of the Council at the meeting in Copenhagen in June of the same year.

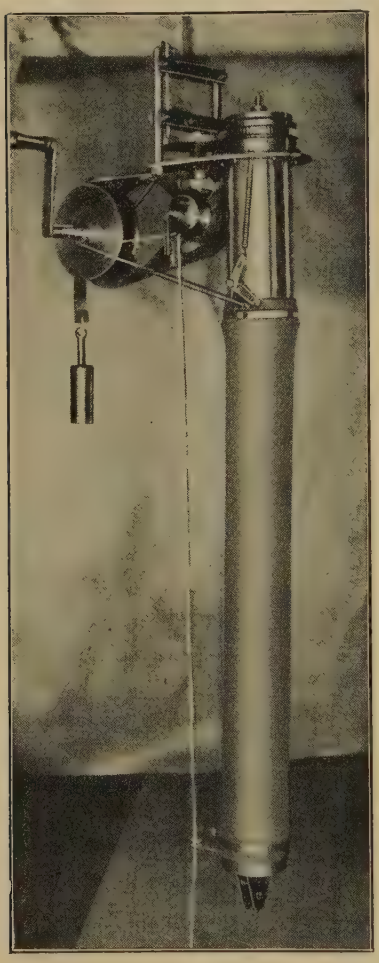

Fig. 1.

I. The quantitative Planktoncatcher with descending weight (Fig. 1).

The type of this apparatus in question, Model PB 1928, (P for PETTERSSON as the inventor and B for its designers and makers, the Engineering Firm PRYTZ & BERTHELSEN, Gentofte by Copenhagen), consists of a strong frame profiled in T-form which has its left horizontal wing bored through in two places to allow of its being fastened to vertical bolts in a solid board, which is supposed to be attached to the bulwark of the ship, across the same and with about two foot of its length protruding over the water. The construction of the apparatus allows of its being laid on deck on the same — left — side without any other parts besides the frame supporting its weight. Into this frame the shafts and other bearing parts are bored or in other ways fitted.

The main parts besides the frame are the magazine wheel for storing the leadline with its removable turning handle and its brake ribbon for preventing the wire from tangling when slackened, weighed down by a small lead, the pulley round which the leadline is passed several times to make it spin, the transmission cogwheels and

the catcher. Other parts are the hinges attaching the crossbar to the frame, and the release, one arm of which is struck by the messenger lead sent down from above for starting the mechanism, and the descending weight or lead suspended to the leadline.

The Catcher consists of one moving part, the propellor, on a vertical axis, constructed at once to suck the water into the cylinder, preventing the mobile zooplankton from escaping upwards and for preserving organisms of a frail or gelatinous build from being damaged in any way. The propellor forming the uppermost part of the catcher, its second part is the cylinder, which receives the water circulated by the propellor and conducts it in a vertical direction down into the rubber gauge, and the nets attached to its lower end. The cylinder can be tightly closed by a valve of ebonite — all other parts being either of metal or bronze — the horizontal axis of which protrudes at one end out of the wall of the cylinder and carries a double lever. The valve can be opened and shut by means of springs acting on the arms of the lever, one vertically stretched from the upper part of the frame, another by means of a short piece of wire slung on the axis of the magazine wheel.

The third part of the catcher is the removable rubber-gauge with the nets inside it and carrying at its lower end the current recorder. The gauge — one meter in length — is fastened round the end of the cylinder by means of a metal belt with a wing screw for tightening it, after the net (or nets-of different mesh) have been tied on. The recorder has two dials with hands giving the quantity of water circulated in respectively 1—10 and 100—1000 litres. The lumen of the gauge is the same as that of the cylinder, or about 12 cm. On the outer wall of the current recorder is a hook fitting round the leadline to keep the gauge in position when the apparatus is descending.

The total weight of the apparatus, apart from the lead, is about 30 kg., and the lead should weigh ca. 15 kg. for attaining the full effect recorded below. The maximal length of leadline to be stored on the magazine wheel is 100 metres with a diameter of 3 mm.

Manner of operating.

a) The Bringing into position and pumping.

The apparatus is slung to an eye at the end of a wire and lowered to the depth desired, though not nearer to the bottom than a distance equal to the length of leadline to be used. A messenger lead is sent down the suspending line to press down the arm of the release and start the weight on the leadline setting

the pulley going and to open the valve inside the cylinder. The movement imparted to the pulley is accelerated 5 times by being transmitted to the propellor by the cogwheels. The water is driven from the propellor by way of the cylinder down through the nets inside the gauge, and is measured by the current recorder. When the whole length of leadline is run out, less the three last turns of the magazine wheel, a spring release will pin the above-mentioned wire connecting the one arm of the lever of the axis of the cylinder-valve to the axis of the magazine wheel, resulting in its being three times wound round the same and consequently shutting the valve and keeping it closed by a considerable force.

b) The sampling of plankton and the winding home of the leadline.

After being started the weight will unwind the leadline at a speed of about 8 metres a minute. Using 100 metres of wire the pumping accordingly will go on for some 12 minutes. Having added this time to the time required for the messenger lead to travel down along the line to the apparatus, one is able to fix the moment for hauling it up again. When lifted out of the water the apparatus is fixed outside the bulwark on the two bolts in the cross board before mentioned.

Then the current record is taken from the dials, after which the gauge is stripped from the cylinder by releasing the wing screw of the belt, whereupon the net can be taken off and the content of plankton dealt with in the laboratory. In the meanwhile the turning handle is applied to the axis of the magazine wheel, and the winding home of the lead easily effected. This done, the valve inside the cylinder, which will open when the leadline is being wound home, is again shut by stretching the horizontal wire on to the release and the apparatus is ready for having the net and the gauge put on and being lowered for taking another sample.

The trials in the open sea show that when a weight of 13 kg. is attached to the leadline the following results were effected by the pumping:—

Plankton net	Weight	Litres per Metre of Wire
None	13 kg.	10.8
Coarse	13 kg.	10.7
Fine	13 kg.	8.8

II. The quantitative planktoncatcher with wire transmission from the ship. (Figs. 2, 3 and 4).

The apparatus includes, besides the catcher itself, a winch specially built for the purpose of working the propellors, by means of a wire transmission.

The diagram (Fig. 2) will show the construction of the catcher. A

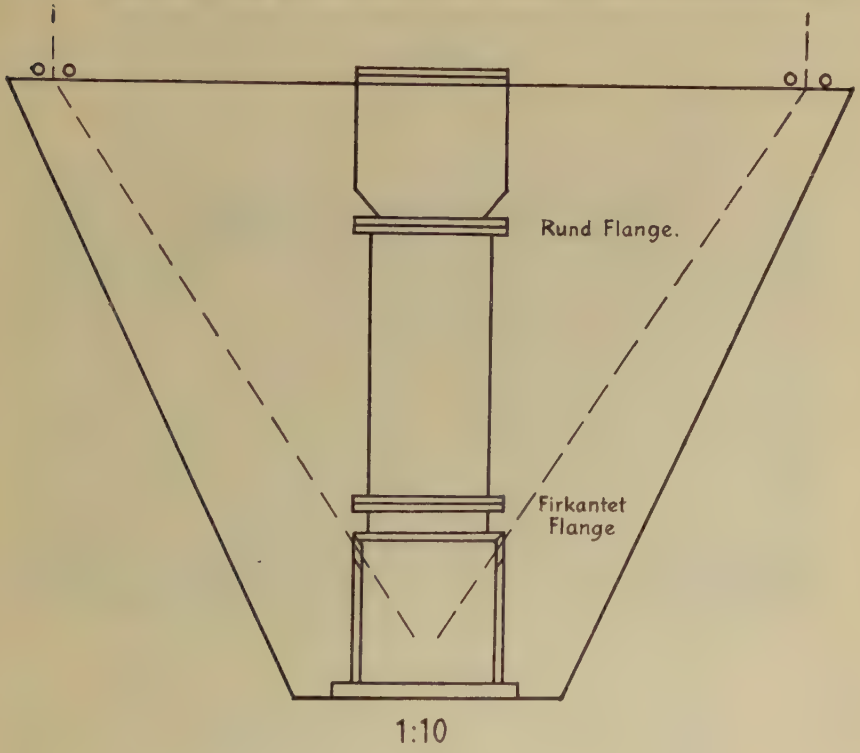

Fig. 2.

strong frame of galvanized L-irons carries the working parts, which are all made of metal or bronze, and protects them from outward damage. The frame is of such dimensions as to keep the two parts of the sling of wire on which the catcher is suspended apart from one another at a distance of one metre, corresponding to the distance between the two barrels of the winch. The reason for this arrangement is first to prevent the two lines from twisting together when worked at the greater depths, and second as far as possible to avoid scaring the bigger mobile organisms of the zooplankton from following the current of water circulated by the propellors, down into the nets.

a) The winch and the transmissions.

Four consols are screwed on to a solid iron plate for carrying the shaft, which consists of two halves to be run separately or in one by means of a clutch on a lever, either by hand or, still better, by means of a reversible motor applied to one end of the shaft. Each half of the shaft carries a line wheel or drum one metre apart from the other, with a circumference of one metre and a width of 20 cm. for storing the line on. The wire of 4 mm. bronze of the softest kind, 600 metres in length, is wound on these wheels, though in opposite ways, offering a "sling" in between for the suspension of the catcher, the wire running in guide

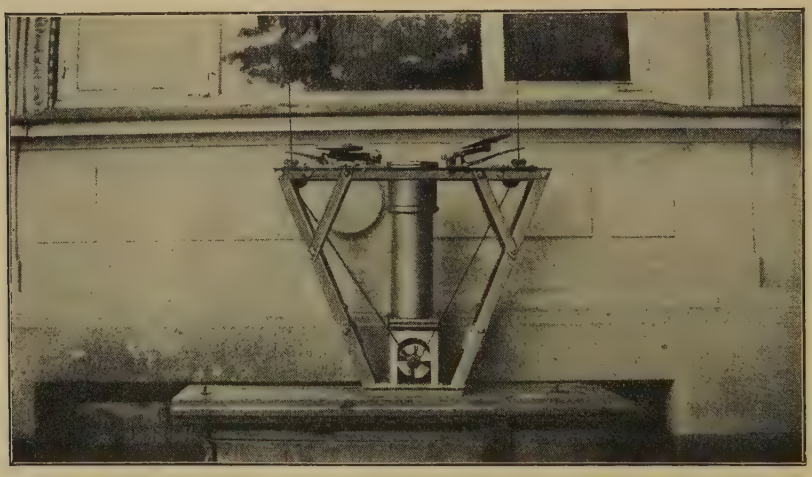

Fig. 3.

wheels inside the frame and wound several times round the pulley to make the propellors work. According to the opposite ways in which both ends of the line are wound on the line wheels, the sling between them is lengthened (or shortened) when only one end of the unclutched shaft is moved, or both halves are moved in opposite directions, as a consequence making the catcher which is suspended in the middle of the sling sink or rise. If the clutch is put on and both halves of the shaft work as one, then the one line wheel will pay out at the same rate as the other will wind the wire home, and consequently the wire will be run through the catcher in one direction or the other, the length of the sling remaining practically the same, thus causing the catcher to retain its position unaltered in a vertical sense.

The shaft will have to be applied inside the bulwark and parallel to same, the iron plate being bored through for fastening to vertical bolts in consols which are screwed on to the bulwark.

b) The Catcher.

Besides the supporting frame, the catcher consists mainly of a vertical tube with a recorder inside at about the middle of its length, and an arrangement for pumping by means of two propellors of reversed action on a horizontal shaft at its lower end. Starting at its upper end

Fig. 4.

the different parts of the catcher tube consequently are the following:—

1) The intake with two different lids and arrangements for closing them in turn applied on the frame, the inside being constructed to receive the net (or nets) for the capture of the plankton.

2) The part containing the current recorder on its outside, recording the amount of water circulated through the nets by means of hands on two dials.

3) The square pumpchamber open at its two opposite ends and having a removable bottom plate with two consols carrying the shaft for the

propellors and the pulley screwed on to it. The pulley by means of a free wheel arrangement only drives the shaft in one direction and consequently is out of action when run by the wire in the other direction.

The lumen of the intake is 18 cm., the outer diameter of the propellors 14 cm. The weight of the catcher and the frame is about 90 kg. This makes its working by hand at the greater depths inadvisable, wherefore combination with a reversible motor will be of great advantage. (See above.) The rather considerable weight might be very much reduced by using less heavily dimensioned material for the frame and plate instead of cast material for the pumphouse and the intake. Nevertheless the heavier weight has the following advantages:—

a) It will keep the catcher tube in a vertical position when the wire is run through it while pumping or for the purpose of vertically changing its position.

b) It will prevent the catcher from being caught and eventually turned round by strong currents which would make both parts of the sling of wire twirl together. If for instance sampling of plankton had to made on board the lightships in the Danish Belts or the Øresund where regular hydrographic and current measurements are taken and where the shallowness of the water makes the possibility with this apparatus to work almost down to the bottom very valuable, a substantial weight would be essential.

Manner of operation.

1) The working of the pump. The catcher, suspended as before mentioned on the sling of wire from the barrels of the winch, is lowered down to the desired depth either by putting the brake on and stopping one drum while the line is being paid off from the other or paying off from both by running them in opposite directions at the same rate. It should be noted that when the catcher is in the desired position and pumping is to be started, as much wire should be left on either wheel or rather so much more on the one from which the line is paid off for working the propellors as will answer to the length intended for the pumping. If for instance 100 metres of wire is to be used for this purpose, and the desired depth for the sampling is 50 metres, the catcher consequently hanging on a sling of wire 100 metres in length altogether, then of the 500 metres of wire left, 300 metres should be stored on the left barrel when pumping is started, assuming the line is put on the pulley so as to work the shaft with the propellors from that side. While transmitting these 100 meter of wire from the left to the right wheel, the catcher for the first 50 metres will descend some inconsiderable

distance and then rise again to its former level when the last 50 metres of line have been run through it.

2) The working of the lids. Of the two lids for closing the intake of the catcher, the one tends to spring back by means of a spring, leaving the opening free for the water to enter when a messenger lead is sent down on the one side before the pumping starts, whereas the other lid in the same way will clap down and shut the intake when pumping is stopped and a second lead is run down the other part of the suspending sling of wire. Both leads work on releases, each arm of which fits round the part of the wire on that side. In this way no water can enter the intake and deposit its content of plankton organisms in the nets, except that circulated by the propellors while the lids are open. By this arrangement also the current recorder is prevented from being influenced by water forced into it when the catcher is descending to the depth where the sample is to be taken.

3) The sampling nets can easily be got hold of when the catcher is lifted with the upper part of the frame at a level with the rail. Lid Nr. 2 is lifted from the intake and thrust back till the release snaps and holds it fast. The ring (or if two nets of different mesh are in use) the rings, on to which the netting is applied, can be lifted up and emptied of their contents.

4) Preventing the catcher from hitting the ship's side in rough weather. For this purpose an experimental davit was constructed which would grasp the catcher as it comes out of the water and, being lifted at the same time as the catcher by the winch, would bring it in safely over the rail on deck. Fig. 4 will give a good idea of this catcher and the way it works.

5) The pumping effect of the propellor for one metre of line run through the catcher according to records derived from trials in the sea at Lofoten, in 1928 as an average result was 565 litres for 100 metres of line viz. 5.65 lit. per metre of wire. The wire was run through the catcher at a speed of about one metre a second. Exact measurements with the nets applied in the intake cannot for the present be given, but their approximate value may be seen from the figures of the trials with the catcher worked by descending weight. (See under I.)

Note on the Growth-rate of Herrings in the Irish Sea.

By

G. P. Farran.

Ministry of Fisheries, Dublin.

In a recent paper on Herring Investigations at Plymouth (Journ. Mar. Biol. Assoc. N. S. Vol. XV, No. 1) Mr. E. Ford has called attention to the importance of taking into account the sizes of herrings at the commencement of a year's growth when comparing the increments made by them during the year, and has published figures showing the average growth made in their second and following years (t_2 etc.) by fish at each successive centimetre length (l_1 etc.) at the commencement of each year, the figures being taken from Sussex and Plymouth samples.

Samples of herrings from the East Coast of Ireland have, with a similar end in view, been examined for some years past by the Department of Fisheries of the Irish Free State and a preliminary summary of the results is given here as a contribution towards the determination of a standard growth rate, in the form of tabulated increments made by fish of successive lengths, which could be used to compare with that from other areas. If such a standard could be established for a large number of localities it would, as Mr. Ford has pointed out, be of great assistance in identifying cases of abnormal migration such as undoubtedly occur from time to time.

As the available samples were small and fish with extreme values of l_1 and l_2 comparatively few it seemed best to group together a number of samples with different numbers of year rings in order to arrive at an average over a series of years.

The herring in these samples were measured, according to the Norwegian method, from the snout to the vertical between the tips of the flukes of the caudal fin in their natural position. The scales were examined either by direct measurement with a squared eyepiece or, more usually, with a projection apparatus, the radial distance from the centre of the

scale to each successive year ring and to the edge of the scale in the middle line being regarded as directly proportional to the length of the fish when they were formed. The growth before the first ring is laid down is, as is usual, referred to as l_1 and no distinction has been made, nor would it be possible to do so, between fish which may have been hatched in late autumn and passed through the winter without forming a winter ring and those hatched in the spring and summer of the following year. The winter ring is assumed, for statistical purposes, to be laid down on 31. December in each year and consequently herrings landed on 1st January would be credited with one more ring than if they had been landed on the previous day.

In estimating the second year's growth two sets of samples were examined. The first set, consisting mainly of fish over three years old, was as follows:—

Date	Locality	No. of Specimens	Year rings per cent									
			I	II	III	IV	V	VI	VII	VIII	IX	X
14. 7. 21	off Howth	51	..	22	22	35	18	4	..	..	..	..
11. 7. 23	—	119	..	16	55	23	6	..	..	..	..	..
24. 7. 23	—	149	..	36	47	10	2	3	2	1	..	..
11. 8. 23	—	154	..	..	3	14	37	25	14	6	1	..
13. 2. 24	Dublin Bay	113	..	2	25	57	12	3	..	..	..	..
23. 7. 24	off Howth	144	..	3	6	23	24	25	8	5	3	..
20. 8. 24	—	175	..	17	9	10	13	22	15	9	4	1
30. 7. 25	—	59	..	3	7	2	24	27	24	8	2	3
14. 8. 25	—	187	..	8	5	10	24	24	15	10	3	..
13. 7. 26	off Arklow	222	..	17	55	15	6	5	1	1	..	..
21. 7. 26	off Howth	194	1	61	23	7	3	4	1	..	..	..
5. 8. 26	—	150	5	70	13	4	1	3	1	1	1	..

The Howth fish were taken E. to NE. of Howth, ten to thirty miles off.

Only fish having three or more year rings have been tabulated from these samples as it seemed probable that younger fish would be exposed to selection from two causes, one, that the gill-nets used were not adapted to the capture of two ringed fish of slow growth, and the other, that the more rapidly growing fish with less than three winter rings may perhaps separate themselves from the smaller of equal age and attach themselves to shoals of older fish.

In the following table the total number of fish with three or more winter rings examined from these samples are grouped together according to their l_1 lengths, as calculated from their scale measurements, in 1 centi-

metre groups and the actual number of fish at each centimetre length of l_2 is given for each group. The original records are made to the nearest millimetre and all fish bearing the same centimetre number are grouped under their central value, thus all fish from 20.0 to 20.9 cm. are grouped under 20.5 cm.

l_1 cm	Second season's growth = l_2 Numbers at each cm. length													Numbers	Mean l_2	Increment = t_2
	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5	24.5	25.5			
7.5	1	3	1	10	5	10	2	..	..	..	..	..	..	..	32	16.16	8.66
8.5	..	..	6	3	17	25	10	1	..	..	..	..	..	..	62	17.03	8.53
9.5	..	1	2	5	18	27	24	8	1	..	..	..	..	..	86	17.56	8.06
10.5	..	..	1	6	17	22	51	36	8	1	..	..	..	..	142	18.34	7.84
11.5	..	..	..	1	4	12	35	52	16	3	..	..	..	..	123	19.07	7.57
12.5	..	..	..	..	..	7	32	66	32	9	5	1	..	..	152	19.65	7.15
13.5	..	..	..	..	..	3	19	47	59	24	3	..	..	..	155	20.09	6.59
14.5	..	..	..	..	..	..	8	24	40	61	18	1	..	..	152	20.89	6.39
15.5	..	..	..	..	..	..	1	7	43	41	18	3	..	..	113	21.18	5.68
16.5	..	..	..	..	..	..	..	4	18	38	23	7	..	..	90	21.62	5.12
17.5	..	..	..	..	..	..	..	..	2	10	10	5	4	1	32	22.56	5.06

The second set of samples consisted mainly of fish which were completing or had just completed their third season's growth. They are representative of a class of herrings which are taken close to shore every winter along the coasts of Dublin, Wicklow and Wexford, sometimes in very large numbers. These samples were as follows:—

Date	Locality	No. of Specimens	Year rings per cent					
			I	II	III	IV	V	VI
7. 11. 22	Dublin Bay	97	24	64	9	3	..	..
8. 11. 22	Howth	212	1	87	9	1	..	..
10. 1. 23	Arklow	234	..	8	82	8	1	..
14. 10. 25	—	116	6	84	7	1	..	2
10. 12. 25	Courtown	189	9	83	6	1	..	..

In the case of these samples it is unlikely that much selection has taken place, for although gill-nets were used, they were of a mesh suitable for the capture of small fish, and the composition of the samples suggests that a complete year class was adequately represented in each. The fish with two winter rings, or, in the case of the sample of 10. 1. 23, with three winter rings, have been tabulated to show their second season's

growth for comparison with the growth rate given above from examination of older fish.

l_1 cm	Second season's growth = l_2 Numbers at each cm. length											Numbers	Mean l_2	Increment $= t_2$
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5			
7.5	..	5	9	7	7	4	..	..	..	..	..	32	16.37	8.87
8.5	2	4	7	18	12	10	1	..	..	..	..	54	16.76	8.26
9.5	..	..	4	14	17	19	2	3	..	..	..	59	17.67	8.17
10.5	..	..	4	12	21	28	19	2	..	..	..	86	18.10	7.60
11.5	..	..	..	4	16	47	39	6	1	..	..	113	18.76	7.26
12.5	..	..	..	..	9	27	51	12	3	..	..	102	19.23	6.73
13.5	..	..	..	..	..	10	28	17	4	1	..	60	19.80	6.30
14.5	..	..	..	..	..	2	15	13	12	..	..	42	20.33	5.83
15.5	..	..	..	..	..	..	4	21	21	5	1	52	21.08	5.58
16.5	..	..	..	..	..	..	..	4	15	14	1	34	21.85	5.35
17.5	..	..	..	..	..	..	..	1	8	4	3	16	22.06	4.56

To facilitate the comparison of these two sets of samples they have been plotted together in a diagram (Fig. 1) showing the increment (t_2) for each successive length of l_1.

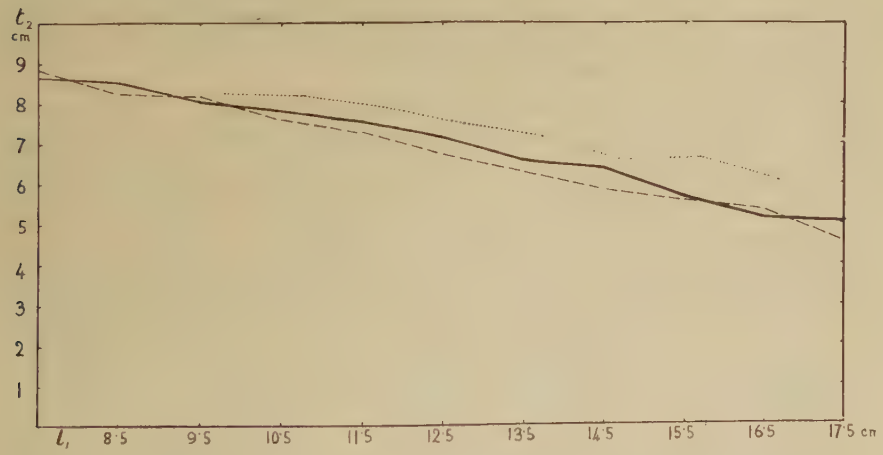

Fig. 1. Increment in second year. The abscissae show the lengths at the formation of the first winter ring, the ordinates the increments made by fish of each successive length.

Thick line, samples from E. Coast of Ireland with 3 or more than 3 w. r.
Broken line, samples from E. Coast of Ireland with 3 or fewer w. r.
Dotted line, Plymouth sample.

The growth rate of the Plymouth samples as recorded by Ford has also been plotted on the same diagram but it has not been possible to do this directly from his figures as his measurements have been made in a different manner, the total length of the fish being measured from the snout to the tip of the longest ray of the dorsal fluke of the caudal fin bent down parallel to the body.

It is necessary to convert these measurements to the Norwegian scale by applying a "correction" and this can most easily be done by subtracting $^1/_{50}$ from the length of the fish, measurements of a large number of herrings of different sizes by the two methods having shown that the difference between them is approximately 2 per cent of the length of the fish. The following table, in which the observed lengths of the Plymouth fish have been taken, shows the result of this conversion.

l_1 (Ford)	9.5	10.5	11.5	12.5	13.5	16.5	15.5	16.5	cm.
l_1 (converted)	9.31	10.29	11.27	12.25	13.23	14.21	15.19	16.17	-
l_2 (Ford)	17.93	18.87	19.58	20.15	20.82	21.22	22.29	22.67	-
l_2 (converted)	17.57	18.49	19.19	19.75	20.40	20.80	21.84	22.24	-
t_2	8.26	8.20	7.92	7.50	7.17	6.59	6.65	6.07	-

It will be seen from the diagram that there is a very fair agreement between the two Irish sets of samples, the older fish showing a slightly higher average growth rate in their second season, suggesting that there may be an infiltration from some region where nourishment is more plentiful. The Plymouth samples have a distinctly higher growth rate than either of the Irish Sea samples.

The growth increment (t_3) for the third season has in like manner been calculated for Irish Sea fish, using all fish with three or more winter rings from the first set of samples used above in estimating t_2 and from one sample, that of 10.1.23, in the second set of samples.

The resulting figures are tabulated below:—

	Third season's growth = l_3 Numbers at each cm. length											
l_2 cm.	18.5	19.5	20.5	21.5	22.5	23.5	24.5	25.5	26.5	Numbers	Mean l_3	Increment $= t_3$
16.5	..	7	34	41	12	3	..	..	..	97	21.18	4.68
17.5	1	4	19	59	47	4	..	..	..	134	21.69	4.19
18.5	..	..	2	70	111	26	4	..	..	213	22.30	3.80
19.5	..	..	..	18	113	114	19	1	..	265	23.02	3.52
20.5	..	..	..	3	44	100	64	6	..	217	23.62	3.12
21.5	..	..	..	..	7	49	98	36	..	190	24.36	2.86
22.5	..	..	..	..	..	2	22	41	6	71	25.22	2.72
23.5	..	..	..	..	..	..	2	4	8	14	25.93	2.43

The growth increments of Plymouth fish, as shown by FORD's observed figures, converted to the Norwegian scale by the above mentioned method, are as follows:—

l_2	(Ford)	16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5	24.5	cm.
	(conv.)	16.17	17.15	18.13	19.11	20.09	21.07	22.05	23.03	24.01	-
l_3	(Ford)	21.00	21.87	22.76	23.50	24.02	25.06	26.11	26.79	(27.33)	-
	(conv.)	20.58	21.63	22.32	23.03	23.54	24.56	25.59	26.25	(26.78)	-
t_3		4.41	4.28	4.19	3.92	3.45	3.49	3.54	3.22	(2.77)	-

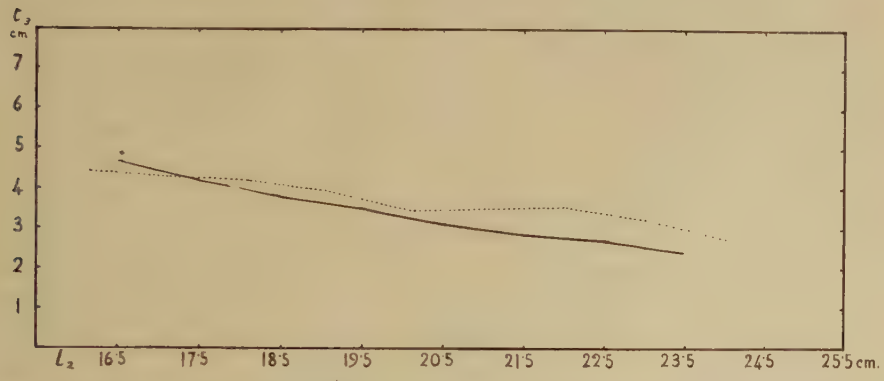

Fig. 2. Increment in third-year. The abscissae show the lengths at the formation of the second winter ring, the ordinates the increments made by fish of each successive length.

Thick line, samples from E. Coast of Ireland.
Dotted line, Plymouth samples.

If the graphs of the Irish Sea and Plymouth fish are compared (Fig. 2) a noticeable difference is evident. The fish with l_2 of 16.5—19.0 cm. put on approximately equal increments in both localities but the fish which started the year at sizes above 19 cm. show in the Plymouth samples a much higher and more irregular growth than those from the Irish Sea.

It would be premature to speculate on the cause of this difference, which may be due merely to insufficient sampling, until a definite correlation has been determined, as far as is possible, between the annual increment made by a large and a small herring of the same year group under identical conditions, assuming that the original difference is due to differences in the date of hatching and in previous nourishment and not to racial or physiological causes.

Mr. Ford suggests that the graph of these annual increments can be represented by a straight line but this suggestion does not seem to meet the state of affairs found on the East Coast of Ireland, and it is partly in the hope of eliciting data from other localities bearing on this question, which appears to be a fundamental one in herring investigations, that this note is published.

Experiments in Transplanting young Plaice from the North Sea and the Limfjord to the Belt Sea and adjacent Waters in the Spring of 1928.

By

A. C. Johansen.

The great development of the plaice fishery in the Belt Sea and the adjacent waters during the period 1910—20 raised the yield of the fishery to a height that could not be maintained permanently. A disquieting fall in the yield has occurred since the end of the war, and year by year the yield in weight has diminished. Whereas the total annual yield of the plaice fishery in the Belt Sea during the two last years before the great war (1912 and 1913) was ca. 3.000 tons, and during the two first years immediately after the war (1919 and 1920) ca. 2.400 tons, it has decreased in recent years to ca. 1.000 tons. We are seeking for some means to counteract this enormous diminution in the yield and are devoting our attention especially to a more rigorous protection of the fish than that which is at present in operation and also to introducing fish from the North Sea or the Limfjord.

The average weight of the marketable plaice caught in the Belt Sea is about 250 grams per fish and the number of plaice caught annually by fishermen in recent years amounts to about 4 million. In addition to this we must reckon that some million are destroyed each year by fishing operations before they attain a marketable size, and that the enemies of the plaice — especially cod — also destroy a considerable number. It is thus clear that if the fishery is to receive effective assistance, by young fish being introduced from other regions, several million must be planted annually.

The transplantation carried out during this year in April and at the commencement of May has been of an experimental nature and has

involved the use of only about a million fish, but it may nevertheless be assumed that the experiment has been so comprehensive that the effect of the plantings in several places will be perceptible to those engaged in the commercial fishery. It is possible to a certain extent to ascertain how great a percentage of the catch is derived from the plaice transplanted from the North Sea and the Limfjord, since these have a greater number of fin rays than the Baltic fish.

In comparison with the plantings in the Belt Sea, those in the adjacent waters have been inconsiderable, as may be seen from the figures given below:

	Number of fish transplanted
Belt Sea	ca. 1,044,000
Western Baltic	111,000
South-western Kattegat	169.000
Isefjord	34.000
Øresund	41.000
Baltic off the shores of Sealand and Møen	31.000
	ca. 1,430,000 fish

The aggregate weight of the transplanted fish was ca. 103,000 kilograms. The transplanted fish originated from the following regions:—

	Weight in kg	Number
Nissum Broad, Limfjord	39.200	743.000
"Thyborøn"	28.500	356.000
Horns Reef Area	35.300	331.000

The fish from "Thyborøn" were mixed, some being caught in the western portion of Nissum Broad, others in the North Sea in the neighbourhood of Thyborøn Channel. Both these fish and those from Nissum Broad were transported from the place of capture to the place of liberation in well smacks carrying from 2.500 to 3.500 kilograms. The fish from Horns Reef Area were transported partly by motor lorry and partly by rail from Esbjerg to Fredericia, where they were kept in floating boxes for about 5 days prior to liberation. At the places of liberation (see the figure on p. 369) the fish were scrutinized as to condition and quantity by fishery officials on board steamers belonging to the Fishery Board ("Falken" and "Havørnen") and the price agreed upon for the fish was paid only for those which were judged to be in good condition.

The length of the transplanted fish varied from ca. 14 to 27 cm. and the average weight was as follows:—

	Weight per 100 fish
Fish from Nissum Broad	5.28 kg
Mixed fish from Thyborøn	8.00 -
Fish from Horns Reef Area	10.66 -

The cost of the transplantation, which was defrayed by the Danish State, amounted to ca. Kr. 45,000 or a little over 3 øre per fish.

SKAGERRAK
THE NORTH SEA
KATTEGAT
JYLLAND
FYEN
SJÆLLAND
Laaland
WESTERN BALTIC
The Sound
Skagen
Göteborg
Frederikshavn
Hirtshals
Hjørring
Thisted
Hanstholm
Thyborøn
Nissum F.
Ringkøbing F.
Esbjerg
Fanø
Fanø Rev
Horns Rev
Fredericia
Aarhus
Randers
Aalborg
Viborg
Silkeborg
Helsingør
Helsingborg
Kalmstad
Falkenberg
Varberg
København
Roskilde
Malmö
Falsterbo
Nyborg
Svendborg
Odense
Assens
Faaborg
Rudkøbing
Nakskov
Flensborg
Kiel
Lübeck
Travemünde
Neustadt
Warnemünde
Rostock
Stralsund
Gedser
Rødvig
Moen
Falster
Ærø
Als
Sylt
Rømø
Amrum
Skagen
Frederikshavn
Hirtshals
Thisted
Hanstholm
Thyborøn
Esbjerg
Fanø
Fredericia
Aarhus
Randers
Aalborg
Viborg
Silkeborg
Helsingør
Helsingborg
Kalmstad
Falkenberg
Varberg
Göteborg
Skagen
Nissum F.
Ringkøbing F.
Horns Rev

The transport of the fish was to all appearances carried out successfully. Only two or three per cent. of the fish died during transport and only two or three per cent. of the live fish were injured so badly that they had to be rejected when the places of liberation were reached. The fish transported by land seemed to be just as lively when liberated as those transported by well smacks from the place of capture to the place of liberation, and this fact is of the greatest importance for the planting of fish in the Belt Sea and western Baltic, since the fish transported by land can be supplied to these waters at much less expense than those transported by well smacks from the Limfjord or the North Sea.

In order to obtain information as to the growth and migrations of the fish planted, and in order to collect some data as to their behaviour in general, 3000 of these fish were marked at 30 different places where liberation took place. In addition 430 plaice were marked at the places where they were captured in the inner Danish waters. The aim of these two series of investigations was to ascertain whether there are any differences between these two groups of fish as regards mortality, growth and migrations.

Up to now no differences have been observed in respect of the migrations and the rate of growth of the two groups of fish, but there has been a marked difference as to the percentage of recaptures. Of the marked transplanted fish not nearly so many per cent. have been recaptured as of those indigenous to the Belt Sea. This fact seems to suggest that the mortality caused by other factors than fishing operations has been far greater in the first group than in the latter.

Materials for the Study of the Productivity of the Sea-Bottom in the White, Barents and Kara Seas.

By

L. Zenkewitch, V. Brotzky and **M. Idelson**

from the Laboratory of the Maritime Scientific Institute, Moscow.

In the last six years, several scientific researches have appeared in Russia on the productivity of the sea-bottom: by N. Tchugunoff on the Azov[1]) and Caspian[2]) Seas, by L. Zenkewitch[3]) on the White and Barents Seas. Analogous research work has also been carried on in the Black Sea (N. Tchugunoff), the Sea of Japan (Pacific Ocean Scientific Fishery Research Station), and the Kara Sea (Marine Scientific Institute); the results obtained through the study of the collected material will shortly appear in print. Thus, the quantitative evaluation of the benthos holds an important place in all scientific work in Russian waters. The Marine Scientific Institute began to investigate the productivity of the sea-bottom in the White, Barents and Kara Seas in 1924. The authors of the present paper, having taken part in the expeditions of the Mar. Sc. Inst., on the "Persey", were able to collect much valuable material. Some of it is already worked out, the rest is being studied. In this article, the authors wish to summarize the general considerations which are the result of four years of scientific work. Besides the researches

[1]) N. L. Tchugunoff. Vorläufige Ergebnisse der Untersuchungen über die Produktivität des Asowschen Meeres. Abhandlungen der Wissensch. Fischerei-Expedition im Asowschen und Schwarzen Meer. Lief. 1, 1926. (See review in this Journal, p. 391).

[2]) N. L. Tchugunoff. Essay on the quantitative exploration of the benthos-production in the northern part of the Caspian Sea. Reports of the Ichthyological Laboratory in Astrachan. Vol. V. No. 1, 1923.

[3]) L. A. Zenkewitsch. Materialien zur quantitativen Untersuchung der Bodenfauna des Barents und des Weissen Meeres. Berichte des Wissenschaftlichen Meeresinstituts. Bd. II, Lief. 4, 1927.

of L. Zenkewitch, already published, other articles are in the press, on the productivity of the bottom of the Stor-fjord in Spitzbergen (V. Brodsky), the central part of the Spitzbergen bank (M. Idelson), the Kildin bank near the Kola bay (M. Idelson), the northern part of the Barents Sea (V. Brodsky) and the Kara Sea (V. Brodsky). As to the southern part of the Barents Sea, the most important one for the fishing industry, although considerable materials have been obtained here, it requires further investigation. Such work is in progress, and the material obtained will also be published. Thus, we possess already the necessary elements for sketching the general outlines of the productivity of the sea-bottom in these regions. In our investigations, we dealt scarcely at all with the littoral region, as the expedition carried on its work chiefly in the open sea. On the other hand, the immensity of the area to be investigated permits us only occasionally to make a closer net of stations, of the degree of closeness which is desirable for work with a bottom sampler. The usual intervals between the stations in the open sea are of 30 sea miles. For the region of the Petchora and the White Sea, the distance between the stations was smaller. It has been possible to cover the region about the Kanin-peninsula by a net of 80 stations, with an interval of ten sea-miles between them. Occasionally, in particular areas, the interval between the stations was brought down to 5, 3 or even one mile. For instance, the Kildin bank was crossed by a row of 27 stations, separated from each other by an interval of one mile. In the course of the investigations, the bottom sampler has been worked at 500 stations, and 1200 samples altogether have been taken.

All the numbers given further on represent the alcohol weight. In the rough conditions and environment of the cruises at sea, it has been utterly impossible to determine the rough weight. However, extensive material is being collected as to the loss of weight of different marine animals when preserved in alcohol, and we hope, in the immediate future, to add the necessary corrections to all our evaluations. This will reduce to a minimum the errors due to alcohol fixation. All the numbers given represent the average numbers for a particular area, obtained by means of many samples. Very large variations as to the amount of the production exist in different areas of our seas. Areas are not rare, where the benthos (e.g. in shell, gravel, coarse grained sand) is almost, or entirely, lacking. Often the production is not above 3—5 gr. per 1 sq. m. But frequently also we find regions with a very high production. The maximum production was discovered in the inland extremity of Maschigin Bay (Novaja Zemlja); it was 3394 gr. per 1 sq. m. We can safely assume

that within the limits of our seas, near the shores, conditions being favourable, a still greater production is possible (for instance, on mussels-beds).

We shall not, in our paper, touch upon particular cases, our intention is only to give a general sketch of the open parts of the Barents,

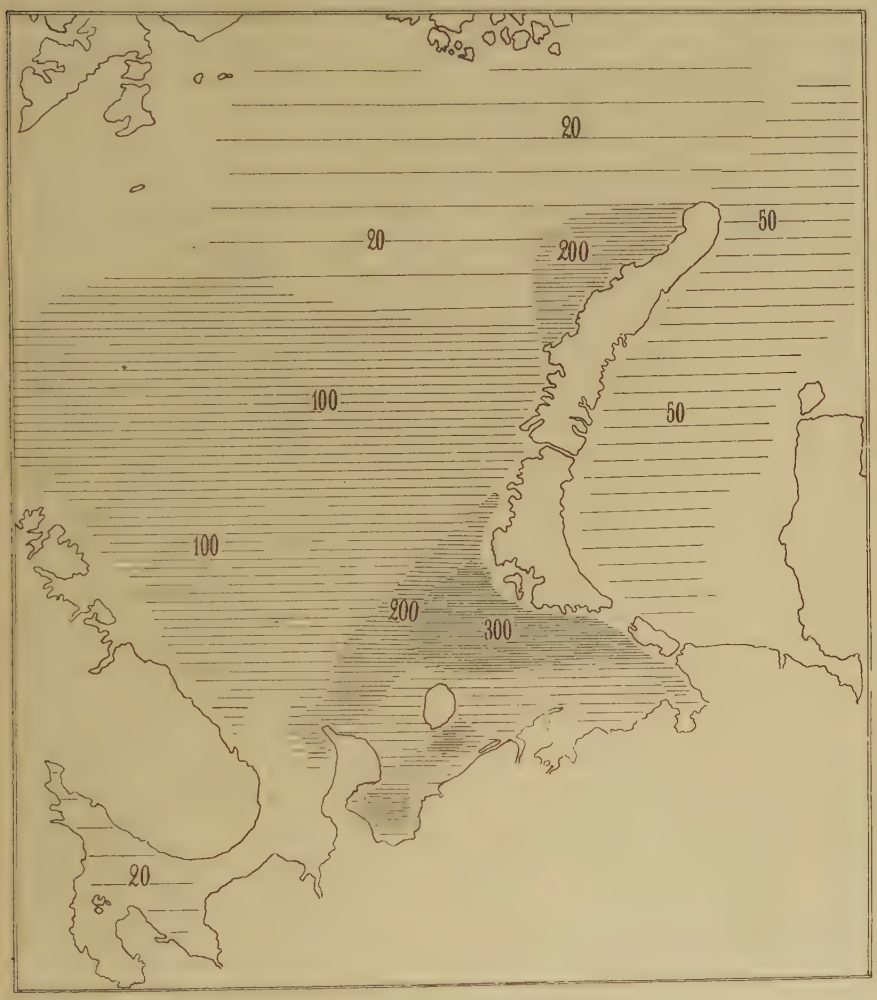

Fig. 1.

Kara and White Seas, and especially, of the muddy and sandy-mud-bottoms.

Fig. 1 represents the area we have investigated; the more or less close hatching corresponding to different degrees of productivity, from 20 to 300 gr. per 1 sq. m. One can see that in the central and southern parts of the Barents Sea, the density of the bottom organisms (average

production) is about 100 gr. per 1 sq. m, and increases gradually towards the south-east. After passing the region about Kanin, with an average production of 100 gr. per 1 sq. m, we penetrate into the northern part of the Petchora region, where the mean production rises to 300 gr. per 1 sq. m. It is necessary to note that in the central and the southern part of the Barents Sea, at isolated points, a production was discovered surpassing the averages given above. These points are mostly the borders of the shallows, and we will speak of them later on.

This distribution of production in the Barents Sea is evidently connected with the migration of the cod and the haddock and with the distribution of some other fishes of industrial importance. The cod and the haddock, in moving eastwards, keep for the most part along the edges of the shallows, their final goal being the Petchora waters and those near the Kanin peninsula, where food is plentiful.

As the investigations of the Mar. Sc. Inst. have shown, in the years when the temperature conditions are favourable the cod and the haddock go far east in the Petchora region, as far as the island of Vaigatsh and penetrate in small quantities even into the southern bays of Novaja Zemlja.

If we move to the northern part of the Barents Sea, we find ourselves in a region with a very poor bottom population — about 20 gr. to 1 sq. m. on an average. The same small productivity of the sea bottom characterizes all the central part of the White Sea. The central part of the Kara Sea also gives a low average (about 50 gr. for 1 sq. m).

What are the factors of the external environment that determine this distribution of density in the benthos? Of course, the most powerful factor must be the distribution of the detritus, and we will, further on, consider this. But the poor production of the White, Kara and Northern Barents Seas cannot be attributed to an insufficient affluence of detritus. The factors of temperature, salinity and depth must likewise be eliminated. Evidently, here, the presence of some peculiar factor has to be reckoned with, a factor determining the depression of the bottom fauna in those regions where the fauna is poor. We are inclined to consider as such a factor the (unfavourable) gaseous constitution of the bottom water layer.

Fig. 2 represents the distribution of the bottom deposits in the same region. The map, as well as the other data concerning the bottom soil, have been taken from the work of T. Gorshkow, which is being printed in the Report of the Mar. Sc. Inst. One can see that it is just those regions which present an impoverished bottom production, that are covered by brown mud, characterized by a considerable quantity of iron (chiefly

in the Kara Sea and in the North of the Barents Sea), and manganese (chiefly in the White Sea). The quantity of iron in the oxide and dioxide combinations attains sometimes 17 per cent., that of manganese up to 1.75 per cent. Everywhere in these regions ferro-manganese con-

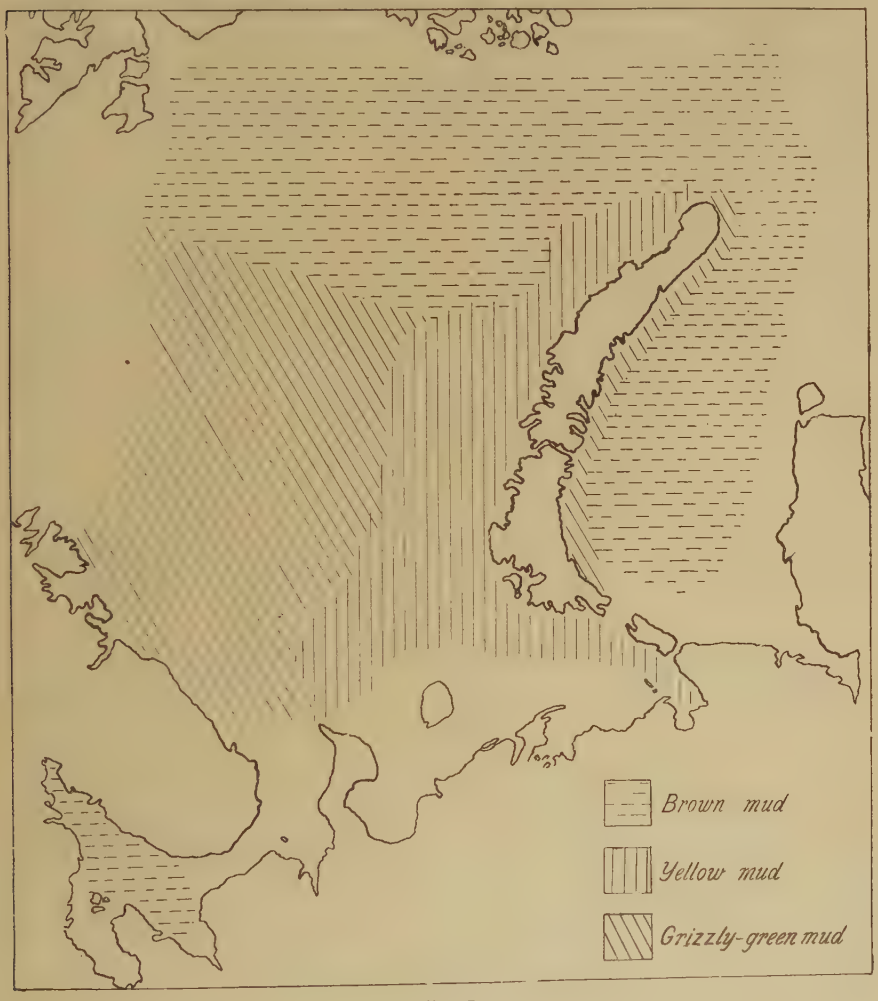

Fig. 2.

cretions are found in abundance. In consequence of the circle of chemical transformations of the iron and the manganese, which take place in the bottom layer itself, with changes from protoxydes into oxydes (action of microorganisms) and *vice versa*, together with an absorption of oxygen, the water becomes richer in carbonic acid and therefore unfavourable to the development of the bottom population. Wherever

we go off the brown coloured ground, we usually come at once into places with a much richer sea bottom fauna. In the present year (1928), we intend undertaking a thorough study of the gaseous constitution of the bottom water layer, in the regions covered with brown muds.

We found the same diminution of the bottom population in the deepest parts of the fiords in the zone of development of the hydrosulphate. If we examine the distribution of the benthos-production, outside of the brown muds, in the regions with a favourable gaseous regimen, it must be admitted that the most important factor is the

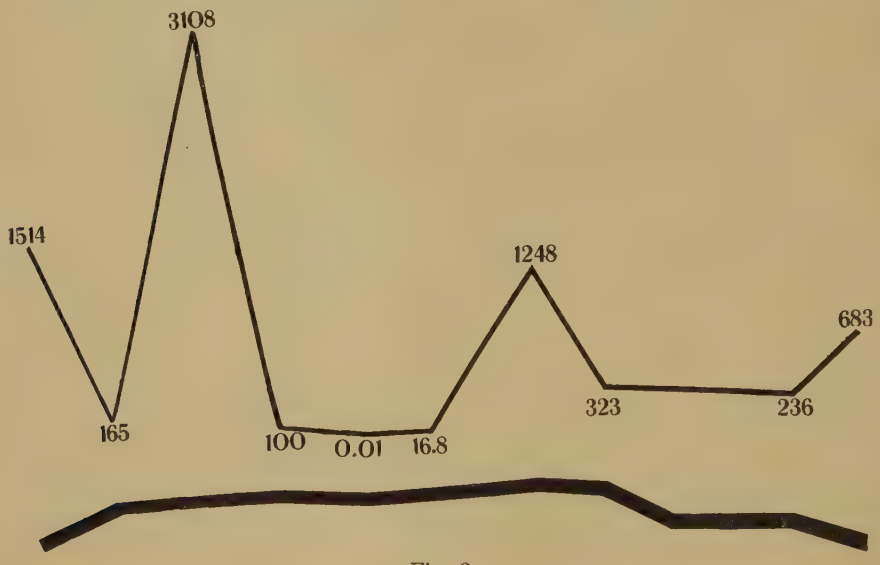

Fig. 3.

incoming of masses of detritus, constituting the staple food resources for the benthos. In this respect, the Barents Sea could be divided into areas with a large, a medium and a small quantity of detritus, settling on the bottom and confined to the bottom water-layer. Evidently, the system of the existing currents has an immense influence on the distribution of the detritus over the bottom basin. In the areas with a great quantity of detritus there will be a luxuriously developed fauna with a predominance of the epi- or the in-fauna, according to the kind of ground. The average production in these areas will be 300—3000 or more gr. per 1 sq. m. Such areas are found chiefly 1) in the bays, creeks and fiords, 2) in the open sea on the edges of banks and shallows. In an area with an average quantity of detritus the production varies from 150 to 300 gr. per 1 sq. m. Lastly, the sections with a small detritus average, principally on sandy and harder grounds (gravel, shells) will present a

production not exceeding 100 gr. to 1 sq. m, but usually less. A good illustration of what has been said is given by Fig. 3 which represents a section of the Spitzbergen bank, according to the data obtained with the bottom-sampler, and below it the profile itself of the bank. The central part of the bank, covered with clean hard soil, is very poorly populated — not above 10 gr. per 1 sq. m. In the places where the slope to greater depths begins, we enter at once regions with a considerably heightened production (1248 to 3108 gr. per 1 sq. m), constituted principally

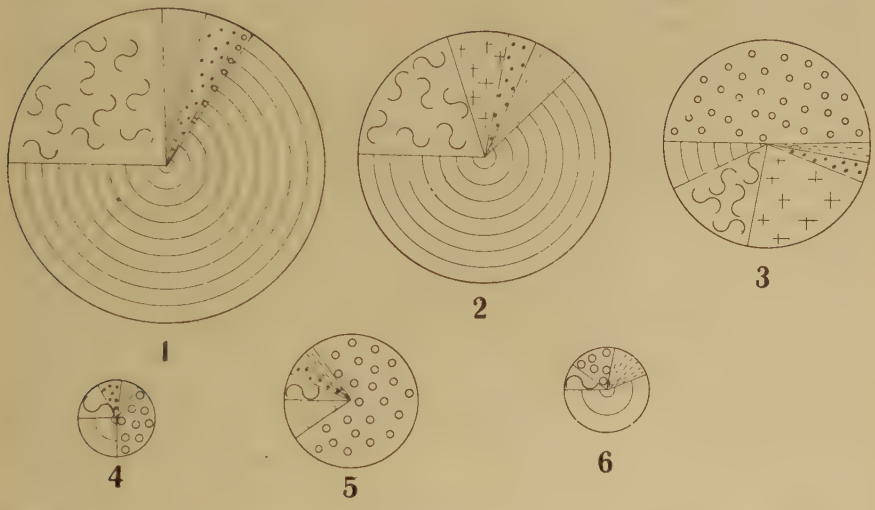

Fig. 4.

by certain forms of the epifauna (e.g. *Cucumaria*). The detritus, washed off here in considerable quantities from the central parts of the bank, does not yet settle at once, but already floats in great quantities in the bottom water layer, and an abundant epifauna feeds upon it. Then on both sides, a considerable diminution of production can be observed.

The infauna does not yet attain its full development, and the epifauna complex typical of a more inshore zone, dwindles to nought. This intermediate zone of an unstable regimen is equally disadvantageous to the epifauna and to the infauna. Then we see again, on both sides, an increase of production up to 683 and 1514 gr. per 1 sq. m. The detritus already

settles here abundantly, the grounds of the bottom are soft and muddy, and an important part is played by the representatives of the infauna.

We consider it absolutely necessary to pay great attention in our future work to the detritus balance in our northern seas, and to the determination of its quantities in the bottom water layer, in different regions.

If we now turn to the composition of the population of the bottom in different areas of the seas investigated, here likewise we can note some items not lacking interest. Fig. 4 represents six circles corresponding to the averages of production for 1) the Petchora region, 2) the Kanin region, 3) the central and 4) the northern region of the Barents Sea, 5) the Kara Sea region, and 6) the White Sea. The surface of the circle corresponds to the number of grammes per 1 sq. m, and the different sectors correspond to separate groups. In the Petchora Sea, the dominant group are the Lamellibranchiata. A very prominent place belongs also to the Polychaeta. The other groups occupy a subordinate position, the Echinodermata especially being feebly represented. In the region about the Kanin peninsula the proportions are much about the same, with the difference that the Gephyrea (*Phascolosoma margaritaceum*) begin to play a rather prominent part, whilst the Echinodermata disappear entirely. In the hauls brought up by the bottom-sampler they are represented by solitary specimens. In the central parts of the Barents Sea, a somewhat sharp change in the composition of the fauna becomes apparent: the Lamellibranchiata constitute here but a small part, the predominating group is the Echinodermata, the Gephyrea come next (*Phascolosoma margaritaceum*), and last the Polychaeta. In the north part of the Barents Sea, the disappearance of the Gephyrea is characteristic. In the Kara Sea, the Echinodermata attain an extremely preponderant rôle, the other groups remaining in the background. In the White Sea, we have a combination, reminding one of the southern part of the Barents Sea. The greater part of the bulk is constituted by the Lamellibranchiata, while the Echinodermata and Polychaeta are well represented.

If we now examine our material from the point of view of the most characteristic communities in it, we must remark that the schema, given previously by C. G. Joh. Petersen[1]) of "the northern community", is, on the whole, exact, and can be altered or completed only in some details. In the central part of the Barents Sea, must be admitted as leading forms: *Astarte crenata*, *Phascolosoma margaritaceum*, *Spiochaetopterus typicus* and *Ctenodiscus crispatus*.

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[1]) C. G. Joh. Petersen. Report of the Danish Biological Station XXI. 1915.

In the Petchora region, besides *Astarte borealis* and *A. montagui*, a prominent place is taken by *Tellina calcarea*, *Portlandia arctica*, *Cardium ciliatum* and *C. groenlandicum*, *Phascolosoma margaritaceum* and *Maldane sarsi*.

For the middle parts of the White Sea, the most characteristic are: *Astarte elliptica*, *Portlandia arctica*, *Leda pernula*, *Ioldia hyperborea*, *Asterias lincki* and *Ophiocantha bidentata*.

For the northern parts of the Barents Sea — *Ophiopleura borealis*, *Ophiura robusta*, *Ophiocantha bidentata*, *Astarte crenata* and *Astarte acuticosta*, *Portlandia intermedia* are to be considered the leading forms in a quantitative evaluation.

In the Kara Sea, we find in the central parts a complex as stable as in the Barents Sea. The principal forms are: *Molpadia arctica*, *Ophiopleura borealis*, *Astarte crenata* and *Phascolosoma* sp.

Besides these representatives of the infauna, various representatives of the epifauna can acquire great importance in different regions, as, for instance, Porifera and Brachiopoda (Kildin Bank), *Cucumaria frondosa* (Spitzbergen Bank), *Strongylocentrotus droebachiensis*, *Ophiopholis aculeata* and *Thelepus circinnatus* (in different regions of the Barents Sea).

Details regarding all the questions here touched upon, will be found in the Reports (Berichte) of the Mar. Sc. Inst. already published and in course of publication.

Note.

New Apparatus for measuring Fish.

This apparatus was designed for single-handed fish-measuring and has been found very convenient for use in open boats where it is not possible to obtain cover from wind, rain and sea which is necessary if records have to be written down on paper. Furthermore it eliminates the possibility of misreading the numbers on measuring boards and renders scaled measuring boards unnecessary, besides freeing both hands of the measurer for dealing with the fish. Its use is so simple and free from error due to the "personal equation" that entirely untrained and illiterate persons can be depended upon to perform good work with it. The apparatus comprises a flat soft wood board of convenient size to hold a few of the fish to be dealt with, a set of celluloid strips 2 inches wide provided with wooden blocks at their ends, and a needle in a handle. One of the wooden blocks is $^3/_4$ inch square in cross section, the other triangular. The celluloid is "unpolished" and about the thickness of thin writing paper. If thicker it tends to crack when bent sharply. The celluloid is glued onto the blocks and nailed with 2 brass nails. Two cabinet makers pins of about $^5/_8''$ long are driven through blocks and celluloid, their ends projecting about $^1/_8''$. For use, a celluloid strip is stretched on the soft wood board and the blocks pushed down to engage the pins in the board. Each fish is laid with its nose against the square block, and the needle is pressed through the celluloid at the point of the tail of the fish. The only thing necessary to guard against is the possibility of pushing the pin through a hole already made in the celluloid, but after a very short time the measurer learns to notice the absence of resistance of the celluloid when this is done. It is best for the needle to be somewhat blunted. The name of the species of fish measured, date of measurement and other details may be written on the strip in pencil

and the pencil-marks resist a surprising amount of rubbing from wet fish. The strips may be cleaned with a wet rag without the pencil marks being removed. If desired, differently coloured celluloid may be used for different fish. I have found that a convenient method for measuring and "otolithing" plaice with the aid of the strips is to draw a vertical line from each pinpoint and to write at the end of the line the age of the corresponding fish. If the otolith is to be preserved, a reference number is written at the end of the line, being repeated on the otolith envelope.

I have to thank Mr. Borley for the suggestion of fixing the small wooden blocks permanently to the celluloid. My original idea was to have the "head-piece" fixed to the board and to pin the celluloid down for use with one end against the headpiece. The latter method is very much cheaper, but certainly introduces a possibility of error in laying down the celluloid. Since the new method was designed primarily with a view to using the services of fishermen for measuring work, it was decided to avoid the possibility of such error by the adoption of Mr. Borley's suggestion which has proved entirely satisfactory. The measurements on the strips are preferably read off through a transparent scaled sheet, the strips either being placed on a sheet of glass arranged with a light reflecting surface underneath it or on a sheet of black material. The measurements may of course be grouped as desired.

I shall be glad to send a sample strip to any interested reader.

Fisheries Laboratory, Lowestoft.

H. J. B. Wollaston.

Reviews.

JAMES JOHNSTONE. An Introduction to Oceanography with special Reference to Geography and Geophysics. 8vo. Pp. IX + 368. Hodder and Stoughton. London 1928.

This recent work by Professor JAMES JOHNSTONE of the University of Liverpool is a second edition of his Introduction to Oceanography, published in 1923, but as mentioned in the preface to the second edition "several of the chapters have been entirely re-written" and "most of the newer results obtained by the physical and chemical investigation of ocean-water are incorporated".

The work is essentially to be regarded as a textbook for the student of geography and geology, and with that object in mind it is natural that a good deal of the space is taken up by geological questions connected with the oceans e.g. the origin and age of the ocean, the origin of the continents, the different points of view as to the history of the ocean and of the earth crust and so on.

The reviewer, having only a superficial knowledge of these problems, has read the chapters dealing with them with great interest. It is felt that on many points the author is able to find good analogies in common experience to explain the great geological hypotheses, which will be of much value to the student.

It is quite clear, as mentioned in the preface to the first edition of the work, that in modern Oceanography physical Oceanography must be treated separately, but while some geological questions are taken into consideration, it also holds good that the connection between the atmosphere and the hydrosphere is of great importance, and though some of such questions are treated in the book it might have been desirable to have treated them rather more extensively.

A chapter entitled "The Depths of the Ocean" contains a survey of the different bathymetrical features and of terminology. Here a graphical representation of the true ratio between the horizontal and vertical scale in a section is of special interest. In the same chapter different instruments for physical investigations at sea are mentioned. Some more detailed description would have been appropriate.

The sea bottom is treated in a separate chapter of about 40 pages and as far as the reviewer is able to judge there is here given a good survey of the different deposits in the sea.

In two chapters — 73 pages in all — are treated the chemistry and the physical characters of sea water. In these chapters the different contents of sea water are dealt with: salinity, gases, nitrogen compounds, hydrogen ion concentration, the compressibility and density of the water, its temperature, viscosity, transparence and various other chemical and physical qualities. Physical and chemical methods are but shortly mentioned, and clearly it has not been the author's intention to produce a textbook for the student on the practical methods of oceanography. More stress is laid upon the distribution of temperature in the sea.

On a perusal of these chapters some statements are found to be to some degree incorrect or the explanation a little incomplete. Among such the following may be quoted:—

P. 142 l. 24. The surface current on the average runs into the Mediterranean. The true explanation is given p. 270. P. 165 l. 17: The intensity of gravity is also influenced by the rotation of the earth. P. 166 l. 26: "Strongly" may be misunderstood. The lamellae in a waterbottle are very thin and rather weak but they are not affected by pressure. It would have been worth mentioning that unprotected reversing thermometers are used in sounding the greatest depths. P. 168 l. 26 and l. 27: There is of course meant the weight of the water alone. P. 169 l. 11: If the density as ordinarily the case is determined as m/l^3 the density of a certain amount of water will be independent of the intensity of gravity. P. 171 l. 29: It is not necessary to have the protecting tube evacuated of air. P. 185 l. 11: There are big differences in the temperature at the surface and at the bottom at some places in the North Sea. P. 200 l. 16: The term "dynamic depths" ought to have been somewhat more accurately explained especially when g is put as 981 (p. 314). P. 200 l. 22: By "sea known to be homogenous" must be meant homogenous in vertical direction only. P. 200 l. 31: Strictly speaking the isobars are not parallel to the surface.

The tides are treated in a separate chapter of 55 pages in which many interesting details are mentioned in such a way that they are easy to comprehend for the student; but of course some difficulties arise, since the problems, according to the plan of the book, must be treated without mathematical symbolism; in particular the deduction of the tide-generating force p. 212 ff. is not clear. The remarks on the effects of long period variations in the tide generating force at the end of the chapter must certainly be taken as hypothetical ones.

The oceanic circulation is treated in a chapter of 48 pages containing a survey of the horizontal and vertical circulation of the water. The problems which here are dealt with are closely connected with much of what has been mentioned in the chapter on the physical characters of sea water, and possibly it might have been opportune to have had the treatment of the distribution of temperature worked out in connection with that of the oceanic-circulation. This is, however, of little importance, but it seems to us that the distribution of temperature, salinity and oxygen might have been used in a more extensive way to elucidate the circulation in the sea. In particular the lack of sections is felt and only a little is said about the movement of the water in the intermediate depths and near the bottom. Some critical remarks of more or less consequence fall to be

made e. g. P. 260 l. 14: The explanation of the sinking down of water from melted ice is not to be adopted. P. 261 l. 6: For determination of the pressure, temperature and salinity must be taken in consideration. P. 261. Fig. 53 and the explanation of it in the text: In computing the directions of the water-movements the rotation of the earth has not been considered. P. 261 l. 17 and P. 262 l. 11: The salinity has not been considered. P. 268 l. 1: It is doubtful if the level of the water in the Gulf of Mexico is considerably raised by the water currents. Differences of level are caused by the distribution of temperature and salinity and these differences to a large extent account for the currents.

The last chapter in the book treats of secular changes in the ocean and is of great interest. Some of the geological problems dealt with in the first part of the book are here subjected to a more detailed discussion and an exposition of the various hypotheses on the history of the oceans is given. The author takes the view that while there is no satisfactory evidence for the elevation of ocean beds to form new continental regions, there is evidence that former continental lands have undergone depression and are now deep ocean beds. The Wegener hypothesis concerning the movement of the continental masses of the earth-crust is not adopted by the author.

As a whole the style and make-up of the book are good.

Only a few misprints are found. On P. 187, Fig. 33 B should read 33 A, p. 209, Fig. 31 should read 37 and p. 16 l. 10 "other" should probably be "outer".

In few of the different branches of science is there a more rapid evolution at the present time than in oceanography and in a work like this prepared for a special purpose, the selection of the material must of course be somewhat arbitrary and result in some oceanographers not finding even the things in which they are interested, but we anticipate that the book will, as intended by the author, be useful as an introduction to oceanography for students of Geography and Geophysics.

J. P. Jacobsen.

T. G. Thompson. The standardization of silver nitrate solutions used in chemical studies of sea water. Journ. American Chem. Soc. vol. L, Nr. 3, p. 681. 1928.

Professor Thompson shows in this paper that using a solution of pure sodium chloride as his standard and accurate pipettes and burettes of the common pattern he can titrate the chlorine of sea water and obtain results in close agreement with those obtained by the use of the Normal Water of Copenhagen and the special apparatus recommended for the purpose. The chlorine of the Normal Water was determined in the first place by expert chemists with every precaution. Professor Thompson, we know on the evidence of other published work, is also an expert chemist, and it would have been inexplicable if he had obtained other results, granting of course the relative accuracy of the atomic weights. The apparatus he uses cannot be read to so small a fraction of a cubic centimetre as the special

pattern, so he uses 25 ccm. of sea water instead of 10 ccm. The only objections to this are the greater cost of the silver used and the larger bulk of silver chloride to be broken up, which probably demands a longer time. But the crux of the whole question is the purity of the sodium chloride. Some oceanographers have stated that pure sodium chloride can be readily purchased. Professor THOMPSON shows that he is not of this opinion. He buys Merck's pure blue label salt, dissolves and filters it, precipitates it by passing in hydrogen chloride, collects and dries the crystals, redissolves them, precipitates with alcohol and dries at 150° C. The average oceanographer has not the skill to carry out this operation properly; in many cases he is a physicist with comparatively small chemical training, or even a biologist. It is to be feared that any attempt to follow Professor THOMPSON's example would lead to the state of confusion which prevailed before the days of the Normal Water and to doubt of any reported change in the salinity of waters of known general constancy, such as the bottom waters of the Norwegian Sea.

Attacks have been made from time to time on the accuracy of the Normal Water. This paper is a welcome and valuable proof that as far as one sample of it is concerned, the attacks are without foundation.

D. J. MATTHEWS.

CHARLES F. BROOKS. Observing Water-surface Temperatures at Sea. U. S. Department of Agriculture Weather Bureau. Monthly Weather Review. Vol. LIV. Nr. 6. Washington 1926.

By far the greater part in the collection of sea surface temperatures used in meteorological and oceanographical studies has been, and must of necessity continue to be, taken by men whose first interest lies in the running of their ship rather than in the scientific study of the observations. Moreover "a degree of accuracy giving temperatures within a few degrees Fahrenheit may be satisfactory for immediate purposes of navigation but not for scientific study". The accuracy with which such observations are commonly made at sea forms the subject of the very valuable investigation which Dr. BROOKS undertook during a cruise in the "Empress of Britain" between New York and the West Indies in the spring of the year.

In the majority of ocean-going ships, sea temperature observations are made in connection with the working of the ship and as part of the co-operative collection of meteorological data.

One set of observations is obtained by the deck staff, the usual method being to drop a canvas bucket from the bridge, and another set by the engine room staff, using thermometers placed at some point in the condenser inlet system. In both cases it appears that the temperature is read to the nearest whole degree Fahrenheit.

The question which at once arises is, what is meant by a "surface" observation? In calm weather, when it is possible for a surface "skin" to exist, it is impossible to sample this skin owing to the disturbance created by a fast moving ship, except from a small boat or by some device operating over the ship's bow. The general consensus of opinion seems

to be that, in general, surface observations do not refer to this thin surface layer in immediate contact with the air, but to the upper metre of water, or thereabout.

How far then are condenser inlet temperatures, which are usually from some 15 to 30 feet below the surface, comparable with surface temperatures, in the ordinarily accepted sense of the term?

Employing a tin (?galvanised iron) bucket to make quick hauls of a full sample, Dr. Brooks first establishes a "standard" to which other observations may be referred, this standard being reckoned accurate to within 0.2° F. Though sampling from over the stern is preferable, it is shown that there is no significant difference between observations made from forward and from aft, the difference being only very slightly greater than the difference between successive observations from the same part of the ship. It follows in passing that the effect of the discharges from the ship on the temperature of the water under the stern is negligible.

By making careful observations of the condenser inlet water temperature (22—24 feet below water) and comparing them with "standard" bucket observations, the conclusion is reached "that in general sea temperatures about a ship are essentially the same fore and aft, both at the surface and at the intake depth". This applies especially in windy weather. On the average the condenser inlet temperature was 0.13° F. higher than the bucket temperature (extreme 0.25° F.).

Regarding the condenser intake temperatures as recorded in the engine room log of the "Empress of Britain", the author concludes that these temperatures "are dependable, and with an average correction of —0.5° F. may be considered in each case as the sea-surface temperature at some point on the ship's course within about 20 or 30 miles of the position of the ship at the middle of each watch". The remarks about the position to which the observations may be referred are necessary owing to the inexactness with which the times of the observations are recorded.

The main source of error in these observations is considered to be the difficulty with which the thermometers could be read; on a few occasions only, differences were found which may have been due to the heating of the water in the pumps.

These conclusions were confirmed in the main by analysis of similar records from the United States Coast Guard ice patrol ships "Tampa" and "Modoc". Moreover, these records bring out some peculiarities of individual observers. In studying the observations taken every hour, the author was struck by the preponderance of changes occurring with the beginning of every watch. The conclusion is reached that "(1) the new observer each watch reads the thermometer differently from the preceding one, (2) that he either does not look at the thermometer or reads it carelessly the second hour, and (3) that he observes it with reasonable care the third hour and probably the fourth".

The usual method employed by the deck staff is to drop a canvas bucket from the bridge and to read the temperature to the nearest whole degree Fahrenheit. The method, a relic of sailing ship days, has changed little since Maury's time.

The sources of error with the canvas bucket method are numerous

and may be differentiated as follows:— 1) the bucket not being at the same temperature as the sea, probably being wet or even having some of the previous sample remaining in it, 2) the sample cooling by evaporation, a) while being hauled and b) while waiting for the thermometer to settle down, 3) the thermometer not being at the same temperature as the sample.

Other errors not directly due to the bucket may be attributed to the thermometer being inaccurate, being read before reaching the temperature of the sample, being withdrawn from the sample for reading, and being indistinct as to marking. Furthermore the quartermasters may be forgetful or "loath to believe their eyes" when marked changes of temperature occur, and inexact in recording the times of the observations.

Comparing his own canvas bucket observations with "standard" observations, Dr. Brooks finds that the average depression of the canvas bucket observations below "standard" was rather more than $^1/_2$° F., there being a noticeable connection between depression below standard and depression of the wet bulb below sea temperature. On the whole, the cooling of the canvas bucket is about 5 to 10 per cent of the depression of the sling wet bulb below sea temperature.

Canvas bucket readings by quartermasters exhibited a still greater deviation from standard. 23 out of 79 hauls differed from standard by —2° to 7° F., the deviations being especially marked in cold winds. The average deviation was 1° F. too low, an amount which, in face of the heavy array of disadvantages which the method presents, is not so great as might be expected, though from consideration of certain other ships' records, the observations from the „Empress of Britain" appear to have been more carefully made than usual. In the case of the "Tampa" and "Modoc" observations, from colder regions, the deviations averaged 3.4° F. too low.

The deviations appear to vary directly with wind strength and depression of wet bulb below sea temperature, and inversely with the quantity of water drawn in the bucket.

As to improvement of the method, it is recommended that the bucket be hung inverted over a ventilator to dry between hauls. The hauling of the sample must be done rapidly since the chief source of error lies in the cooling of the sample while hauling and reading. For this reason, too, little is gained by having more than one dip with the bucket, to bring it to sea temperature. A fibre or paper bucket, as suggested by Dr. Bigelow may be better than the canvas bucket; an iron bucket has the disadvantage of being too easily damaged against the ship's side. Care must be taken to draw a full sample and to protect it from the wind after drawing. Moreover, the work requires the supervision of an Officer.

Notwithstanding the fact that the author considers it perfectly feasible to obtain accurate surface temperatures by the bucket method, he concludes by recommending the thermograph fitted to the condenser inlet.

In the discussion following the reading of the paper, a report of which is given, Dr. Bjerknes emphasised the importance, in identification of the different air streams, of reading the sea temperature to the nearest $^1/_2$° C. He also stated that in Norwegian ships good results were obtained under conditions of frequent inspection, encouragement, and a salary, the wireless operators being the observers.

Mr. J. Patterson said that the Canadian Meteorological Service was able to obtain accurate records of temperature in the North Pacific, from thermographs installed in the condenser intake pipes of certain liners. These thermographs have a range from about 35° to 85° F. on a 3 inch scale, and are considered to be reliable to within 1° F. J. R. L.

K. Brandt. Stickstoffverbindungen im Meere. I. Wissenschaftliche Meeresuntersuchungen. Kiel. XX, 203—292. 1927.

In this scholarly memoir Professor Brandt summarises the results of the varied investigations which have been made concerning nitrogen compounds in solution in sea water, in bottom deposits, and concerning nitrifying bacteria. For particulars of the various investigations, a great number of which were made at Professor Brandt's laboratory, reference must be made to the memoir, but several matters dealt with are of particular interest to oceanographers in view of the investigations now in progress in England, in Germany and in Norway.

In the first place Schreiber has recently found that the green flagellate *Carteria* is capable of obtaining its nitrogen supply equally well from nitrate-, ammonium- or amino-(glycocoll)nitrogen. If this capability were general among phytoplankton organisms, we would expect that both ammonia and "albumenoid ammonia" in the sea would decrease during the summer months, but from the numerous values given by Brandt and from the extensive work of Buch in the Baltic, this does not appear to be the case. Hence it seems probable that diatoms take up their nitrogen requirements in the form of nitrates. This conclusion is fortified by Allen's observation that ammonium will not replace nitrate in a culture medium for diatoms.

The formation of nitrate from ammonium salts in the sea by means of nitrifying bacteria has been shewn to take place in bottom water from the open sea, and in inshore waters, and nitrifying bacteria have been found in bottom deposits, but the presence of nitrifying bacteria in the upper strata of the open ocean has still to be shewn. Unless they are present nitrate can only be renewed near the surface by an upward infiltration of water from below, and this movement is damped down when there is a temperature or density gradient, as during the summer months. The possibility, mentioned by Brandt, that nitrate is formed in the sea from ammonia by means of an inorganic catalyst seems remote. Whereas phosphates are re-formed in the sea by the splitting off of the phosphate molecule from phosphoproteins etc. during autolysis, the re-formation of nitrates probably takes place in two separate stages, the formation of ammonia from nitrogenous organic matter and the conversion of this ammonia by means of nitrifying bacteria into nitrates.

Although the foundations of our knowledge concerning the distribution of nitrate and the part it plays in the plant life of the sea were laid by the work of Brandt and Raben, the method of estimating nitrate which they employed is subject to error. A certain amount of nitrate present in dissolved organic matter was undoubtedly included as nitrate-nitrogen in their estimations. The method employed was as follows. After

boiling off the ammonia from a sample of water, this was digested with aluminium amalgam whereby the nitrates present were reduced to ammonia. This was distilled off and estimated colorimetrically by means of NESSLER solution. Blank determinations with distilled water allowed a correction to be made for any ammonia produced from nitrogen occluded in the amalgam. However, in this digestion with amalgam, ammonia is produced not only from nitrates and from nitrogen occluded in the amalgam (which is allowed for as stated) but also from certain organic compounds such as yield "albumenoid ammonia" and which are present in sea water. Hence there is every reason to suppose that this treatment with amalgam splits off ammonia from organic matter in solution, as it is known to do with natural waters (THRESH and BEALE. The Examination of waters and water supplies. London. 1925).

The values obtained for the nitrate-nitrogen in North Sea waters by this method reached a minimum of 60 to 70 mg. per cubic meter during the summer months, whereas SCHREIBER's method depending upon the growth of *Carteria* in water after filtration indicated that practically no nitrate was present during June in water collected off Heligoland, and the method of estimation by means of reduced strychnine has given values of under 10 mg. per cubic meter for nitrate-nitrogen in the surface water at several positions in the North Sea during the summer.

The distribution of nitrates in the sea and its utilisation by phytoplankton is receiving considerable attention. The work of WATTENBERG in the South Atlantic, of SUND in North Norwegian waters and of the "Dana" now cruising round the world are already yielding results, and additional information may be expected from the "Carnegie" at present on an extended cruise.

The other nitrogen compounds, ammonia and nitrogenous organic matter, appear on the other hand to have an irregular distribution in the sea, with no obvious correlation except that they tend to be maximal close inshore. H. W. H.

F. S. RUSSELL. The Vertical Distribution of Marine Macroplankton. VII. Observations on the Behaviour of *Calanus finmarchicus*. Journal Mar. Biol. Assoc. (N. S.) Vol. XV, Nr. 2. 1928.

Mr. RUSSELL, in this the seventh instalment of the account of his investigations, based on horizontal hauls of a stramin net at serial depths checked by a depth recorder, concentrates his attention on a single species. In previous papers he has put forward evidence to show that in general the depth of the main body of *Calanus finmarchicus*, adult and penultimate stages, is regulated both for its diurnal and annual cycle by the intensity of the light, the optimum depth being less in spring and autumn than in the summer and at dusk than at midday. More detailed observations have shown that this generalization does not hold good in every case and a noticeable exception is the occurrence of adults during July, August and September in the Plymouth samples much nearer the surface than in the preceeding three months. Records of the light intensity and of the ultra violet radiation on the dates on which the samples were taken show

that neither the weather conditions nor the actinic quality of the light sufficed to account for the decrease in depth of the *Calanus* maximum. Mr. Russell in this paper seeks for some other explanation. He finds a tentative explanation in the fact that the sizes of both males and females show a progressive increase from their first appearance in April to a maximum towards the end of May, a steady decrease to the end of July, and a maintenance of this small size till the end of September. This seasonal variation in size is a well attested fact in several species of Copepods and is reasonably assigned to the effect of the temperature at which they were hatched or developed. Mr. Russell suggests that there may be a physiological difference between the large spring brood and the smaller summer brood, the latter preferring a higher intensity of light and consequently living at a higher level in the water.

This suggestion, for it is nothing more, is an interesting one but it is perhaps premature, for the connection between the large and the small broods is by no means clear and there are other possibilities which might be considered. The real value of the paper, however, lies in the detailed information it gives as to the actual vertical distribution under accurately recorded conditions.

The author is also inclined to see in the existance of two broods an explanation for the sporadie appearance of swarms of *Calanus* at the surface in bright sunlight, but this seems hardly sufficient to account for what at first sight seems to be a reversal of the normal reaction.

G. P. F.

Helen S. Ogilvie. Observations on the Food of Post-Larval Herring from the Scottish Coast. Fishery Board for Scotland, Scientific Investigations, 1927, No. 1.

Very little has up to the present time been published on the feeding of the post-larval herring measuring from about 30 to 45 mm. in length. Mrs. Ogilvie has therefore published the results of investigations on the food of these particular stages of the herring from Scottish waters. The fish which form the subject of the investigations consisted of three samples caught on the 17th June 1926 outside Aberdeen Breakwater, the 21st June 1926 off North Pier, Aberdeen and on the 30th April 1925 off Kincardine-on-Forth. The sizes in question varied from 27.5 to 47.5 mm., and the paper is illustrated by photographs of three different specimens, showing the general appearance of the fish.

The food of the herring at this stage consisted almost entirely of copepods, and the main feature of the results was the predominance in each of the three lots of fish examined of one particular copepod, viz. *Pseudocalanus* in the first, *Oithona* in the second, and *Eurytemora* in the third. The predominance of *Eurytemora* in the sample from the Firth of Forth depends, no doubt, on the special locality, as no other of the usual open-sea copepods would generally be found so far up the Firth. The two samples of herring caught off Aberdeen showed rather different results, the copepods *Pseudocalanus* and *Oithona* dominating in each of the samples. The relative numbers of these two copepods taken by the fish were respectively

1258 *Pseudocalanus* per 100 fish and 3703 *Oithona* per 100 fish. In considering this fact, it must, however, be remembered that the nutritive value of a *Pseudocalanus* is undoubtedly several times greater than that of an *Oithona*.

The large percentage of fish found feeding is a point of the greatest interest. The author finds that the percentage feeding was 95.4 and referring to the literature in hand considers this an unusually high percentage. In this connection the reviewer, however, may draw attention to his paper on the food of the herring in Danish waters, published after the appearance of the present work, which shows a similar high percentage feeding for herring of corresponding sizes in Danish waters.

Another point of interest is the abundance of *Oithona similis* in the Scottish material, which is quite different from the results of A. C. Hardy; but undoubtedly this must be due to difference in locality. Anyhow, the abundance of *Oithona similis* in comparison with other copepods in the plankton-samples from the coasts off Aberdeen is very striking, and the relative numbers of this copepod are far greater here than generally found elsewhere in the southern parts of the North Sea.

The present paper, which is further illustrated by two drawings of the two most important copepods, *Oithona similis* and *Pseudocalanus elongatus*, constitutes a very useful and important contribution to our knowledge about the food of the post-larval stages of herring.

P. Jespersen.

N. L. Tchugunoff. Preliminary Results of the Investigation of the Productivity of the Sea of Azov. R.S.F.S.R. National Commissariat of Agriculture. Works of the Azov-Black Sea Scientific Commercial Expedition. Part I. 1926. (From an English Translation by Mr. F. M. Davis of the English Ministry of Agriculture & Fisheries.)

This is an appropriate opportunity to acknowledge indebtedness to those members of the English Ministry of Agriculture & Fisheries who have, from time to time, provided translations of papers by foreign colleagues. In the present instance, thanks are due to Mr. F. M. Davis for his translation of the Russian text.

This paper forms a preliminary outline of the results obtained in a quantitative estimation of the bottom fauna of the Sea of Azov. From one to three hauls of the heavy type of Petersen Grab were taken at each of about four hundred stations arranged in a series of cross-sections of the sea. The very small representatives of the benthos being of considerable importance in this district, special precautions were taken to ensure their inclusion in the samples in the proper proportions. Sieves with 0.5 mm. meshes were substituted for those of 1 mm. normally used in the washing of soils, and a specially devised instrument was employed to remove the small animals retained by them. The apparatus, in its simplest form, consisted of a large crystallisator, heavily darkened on all sides save for one broad strip which was illumined by an electric lamp. The whole sample from the special sieve was placed on the crystallisator and rinsed with water. All actively moving animals which exhibited phototropism soon

collected at the brightly illumined pane of the crystallisator and were taken out periodically with a small scoop constructed of fine metal net. It was found that if the soil was occasionally stirred up, practically every living creature could be removed during the course of a few hours, spending not more than from fifteen to thirty minutes at intervals between other pursuits. Thanks to this method it was established that in some regions enormous quantities of such small species were present which were of the greatest significance in general productivity. Moreover, such species would undoubtedly have passed through the ordinary sieves.

Tchugunoff divides the Sea of Azov proper into a number of districts and zones according to definite ecological conditions, and he describes the various "biocaenoses" peculiar to each. In these descriptions the separate and combined effects of such factors as depths, fundamental soils and hydrographic conditions on the character, distribution and relative abundance of benthic animals are admirably demonstrated. Thus, on a bank composed of compact shelly sand, yellow-red in colour, there exists a complex of animal forms which may be distinguished first of all by their yellow-red coloring resembling the tint of the soil. Or again, in a particular "shell" biocaenosis, the numerous individuals of the genus *Syndesmya* are so distinguishable from those found elsewhere in grey mud, by their more massive shells and faster growth-rate, that they are regarded as a separate "race" peculiar to the "shell" biocaenosis. Equally interesting is the situation presented in the deeper central part of the Sea of Azov where the bottom soil consists of grey mud and blackened shell. In many places this soil has a distinct smell of sulphuretted hydrogen — indicative of stagnant conditions, — so that only a few specialised forms are able to live in it. *Syndesmya*, for example, by reason of the great length of its siphon, which may exceed the length of the mollusc itself some 20—25 fold, is able to avoid the water adjacent to the bottom where oxygen is scarce, and extract the minimal amount of oxygen it requires from the layers above. On rare occasions, however, isolated "nests" of less specialised animals such as *Cardium* and *Corbulomya* are to be met with on tiny hillocks rising from the sea-floor just high enough to allow some of the widely dispersed planktonic larvae of these species to settle down where there is sufficient oxygen to permit them to establish themselves. Periodically, following a spell of warm calm weather, denudation of oxygen in the bottom water layers becomes so acute that many of these "nests" are killed off; — *Cardium* is the first to perish, followed by *Corbulomya*. The age-composition in the *Cardium* nests is very typical; there is a predominance of some one age-group, as the result of the occurrence of an oxygen "famine" followed by a fresh settlement of pelagic larvae. As opposed to this, in other districts where *Cardium* is free to develop in masses and is not subject to "famine", all the essential age-groups are represented.

With regard to the utilisation of benthic animals by fishes, Tchugunoff states that, as in the Caspian, literally all species of the bottom population are used to a greater or less degree. *Syndesmya*, young individuals of *Cardium*, and Polychaeta are the most important as food for the more valuable commercial fishes *Abramis*, *Cyprinus* and *Rutilis*. Not infrequently,

however, adult *Abramis* and *Rutilis* swallow great quantities of the smallest benthic representatives, viz., *Hydrobia* and Ostracoda (*Cytheridea torosa* v. *littoralis*). Under these conditions of such complete utilisation of the food-pastures, it follows that the numerous non-commercial fishes are definite competitors for food. This is compensated for, to some extent at any rate, by the fact that these non-commercial fishes are themselves largely eaten by the commercially valuable ones.

In conclusion, the author deals briefly with the plankton productively of the Sea of Azov. From the first half of the year a great mass development of the blue green diatomic waterplants occurs which imparts definite colour to the water. At such periods the production of plankton may be as high as from 150—175 cc. per 1 cub. metre of water. The zooplankton is of great food value to a whole series of pelagic fishes. Thus, there is an annual spring migration from the Black Sea into the Sea of Azov through the Straits of Kerch, of enormous numbers of Engraulis and herrings for spawning and subsequent wanderings. The rearing of the great mass of fry of these fishes, as well as the feeding of the adults is dependent exclusively on the rich zooplankton of the Sea of Azov. E. F.

D. E. Thursby-Pelham. Report on English Plaice Investigations 1924 and 1925. Fishery Investig. Ser. II. Vol. X. Nr. 3. 1927.

In Fortsetzung der von Borley und seinen Mitarbeitern 1923 und 1925 veröffentlichten Berichte liegt jetzt eine Darstellung der Ergebnisse der englischen Schollenuntersuchungen in den Jahren 1924 und 1925 von Thursby-Pelham vor. Die Untersuchungen sind im Wesentlichen nach dem gleichen Plane ausgeführt wie die früheren und behandeln die Veränderungen des Bestandes nach Menge, Grösse, Alter und Wachstumsgeschwindigkeit der Schollen. Der besondere Vorzug der Arbeit ist, dass sie auf einem ausserordentlich grossen Materiale und der gegenwärtig wohl besten Statistik beruht.

Der erste der drei grossen Abschnitte der Arbeit behandelt die Grösse des Gesamtfanges und des Fanges im Verhältnis zur Befischungsintensität. Der Gesamtschollenfang aller englischen Fahrzeuge in der Nordsee ist seit 1920 zunächst fortgesetzt gefallen und erreichte seinen Tiefstand 1924, während der Fang der Dampftrawler 1924 schon eine geringe Besserung gegen das Vorjahr aufwies. 1925 ist der Fang dieser Fahrzeuge und infolgedessen auch der Gesamtfang wieder deutlich gestiegen. Das ist um so bemerkenswerter, als die Befischungsintensität gerade auf den Jungschollengründen etwas geringer war als 1923. Der Fang pro Befischungseinheit hat in der mittleren und südlichen Nordsee (d. h. südlich von 57°30′) im Jahre 1925 eine nicht unbedeutende Besserung erfahren. Bei den mit Schleppnetzen arbeitenden Fahrzeugen zeigte sich diese Besserung schon 1924. Nach Ansicht des Ref. sehen wir darin die Auswirkung des guten Ausfalls der Brutjahrgänge von 1919 an, die infolge der verringerten Wachstumsgeschwindigkeit erst jetzt fangwürdige Grösse erreichten. — Besonders eingehend wird der Durchschnittsfang der Dampftrawler behandelt. In einer Reihe von Karten ist der Fang pro hundert Stunden in jedem der statistischen Rechtecke dargestellt, und zwar für grosse

Schollen, für kleine Schollen und für den Gesamtfang. Ausserdem ist die Zahl der Trawlstunden in jedem Rechteck in einer ähnlichen Karte eingetragen, sodass man die Intensität der Befischung der verschiedenen Gründe und die Zuverlässigkeit der errechneten Durchschnittsfänge zu beurteilen vermag. Es zeigt sich übrigens, dass die Besserung des Fanges lediglich auf die Zunahme der kleinen Schollen zurückzuführen ist, während die Abnahme der grossen weiter fortschreitet.

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and with those carried out in previous years, notably in certain pre-war years and in September 1922. The first experiment took place in April 1925 when 10 stations were trawled; the total length of time actually spent in trawling was some six to seven hours, but three hauls are not considered since they only yielded one plaice; some 3,470 plaice were measured and 1,535 were otolithed. The second experiment in October 1925 was on a larger scale, since 18 stations were worked and the number of hours hauling was twelve and a half all the 5,459 plaice caught were measured and otolithed. The third, in March 1927, was very short since only two hours trawling took place; six stations were visited of which two only provided one plaice each; 1,697 plaice were measured of which 670 were otolithed.

The material for October 1925 was therefore, by far the most adequate on which to base conclusions. Its examination shows that the age distribution differed widely from that obtaining in the Autumn of 1922 in that there were a far greater number of the 0-I groups in 1922 than in 1925, while in 1925 the older than II groups were the more numerous. The plaice caught, moreover, in 1925 were slightly larger for their age than in 1922. The relative frequency of the various age groups accords very closely with that found by English and German investigators in 1926 and 1927 in that there was an abundance of the 1922 year class and a sparsity of the 1923 and 1924 year classes followed by an improvement in the 1925 class, which however, was not nearly so abundant as that of 1922. The reviewer is inclined to differ from Mr. JENSEN when he ascribes the greater growth rate of the II groups (1923 class) compared with that of the III group (1922 class), as due to the sparsity of the former and abundance of the latter. The English investigations carried out in the summer and autumn of 1926 showed an equal or almost equal rapidity of growth of these two year classes in the Horns Reef and Graadyb area as the III and IV group. The whole question of variations in growth is so complex and bound up with factors other than the sparsity or plentifulness of a particular year group that a variation cannot be ascribed to any one factor, particularly when, as in this case, samples from hauls at so many different areas are grouped together. The same criticism applies to the comparison of the rate of growth between the plaice caught in the Springs of 1925 and 1927. Moreover the material used for the estimation of growth and population for March 1927 was obtained from only one hour's trawling, between 10 and 19 metres, which hardly can be considered adequate for the purpose. The investigators working on the plaice, however, owe a debt of gratitude to Mr. JENSEN for publishing the full particulars of each haul which are valuable for comparison with their own work and with samples taken in the future.

The section on the "Yield by weight of the fishing compared with the size composition of the stock" pp. 36—37 is of particular interest and the catch per 100 hours fishing of English Steam Trawlers corroborates Mr. JENSEN's conclusions. The English figures are as follows:—

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[1]) THURSBY-PELHAM, D. E. Report on English Plaice Investigations 1924 and 1925. Fishery Invest. Ser. II. Vol. X. No. 3. 1928.

Year	1922	1923	1924	1925	1926	1927
Catch per 100 hours (cwts.)	14	12	14	15	16	16

Mr. JENSEN shows that the yield of commercial vessels, with a size limit of 22.5 cms., was poor in 1922 and improved greatly in 1925 and 1926, when the marketable stock was augmented, partly owing to the greater abundance than in earlier years of the year classes of 1920 to 1922, and partly owing to an increased growth rate. He presumes that the marketable stock for 1927 (figures not being available as yet) would be less than that of 1926. The English catch being based on the open North Sea would reflect the conditions found in inshore waters a year later, so the figures are in complete accordance with his conclusions. Taking the results of the work of the English, German and Danish investigators together it is extremely probable that Mr. JENSEN's prophecy that there will be fewer marketable plaice in 1929, will be fulfilled.

It is to be hoped that the Danish Commission will be able to continue this work from year to year on the same scale as in October 1925. It should then be possible, in conjunction with the material obtained by other marine researches, to forecast the probable catch and the effect of fishing on the stock. D. E. T.-P.

MOLANDER, A. R. Undersökningar över Rödspotta (*Pleuronectes platessa* L.), Flundra (*Pleuronectes flesus* L.), och Sandskädda (*Pleuronectes limanda* L.) i södra Östersjön (with an English summary). — Svenska Hydrografisk-Biologiska Kommissionens Skrifter. Ny serie: Biologi. Bd. I, No. 1, 1925. 38 pages, 1 chart, 17 tables, 4 figures in text.

MOLANDER, A. R. Recent Swedish researches into the fish population of the southern Baltic. — Svenska Hydrografisk-Biologiska Kommissionens Skrifter. Ny serie: Biologi. Bd. I, No. 2, 1926. 11 pages, 1 chart, 7 tables, 4 figures in text.

The plaice fishery in the Baltic proper which before the war was of practically no importance has developed enormously during the last ten years; a very large number of Swedish, German, and Danish fishermen are now engaged in it and an annual yield is obtained which equals if it does not exceed the yield from the Kattegat and Belt Sea.

It is therefore extremely interesting to study the influence which this new and very intensive fishery has had upon the plaice stock of the Baltic, and fortunately we possess good comparable material which has been furnished by previous investigators. Comprehensive investigations bearing on this question have in fact been carried out by Swedish, German, and Danish biologists; the works by Dr. MOLANDER cited above deal with the results obtained from the Swedish investigations carried out in 1913 -25.

The first of these works treats of plaice, flounders, and dabs and discusses in particular the reason for the seasonal migrations of these fish. The material is derived from about 200 trawlings from S.S. "Skagerak", during the periods 1913—16, 1918—19, and 1921—22, partly in the Arcona Basin and partly in the waters around Bornholm.

1. Plaice. The author points out that whereas plaice were comparatively scarce in the Arcona Basin (depth, 40—50 m.) the bulk of the plaice were found in the deep water (depth, 70—80 m.) to the north of Bornholm; in the deep to the east of Bornholm (depth 60—79 m.) the numbers again decreased. In winter the plaice congregate in the deep to the north of Bornholm, a corresponding reduction taking place simultaneously in the numbers of plaice in the shallower parts of the Bornholm area and the Arcona Basin. In summer an upward migration occurs from the deep up to the shallower waters, but this does not include the large plaice (over 30 cm. in length) which remain for the most part in the deep water. This upward migration of the smaller plaice takes place, according to the author, as late in the year as July—September as far as the bulk of them is concerned; in October—November the plaice begin to seek the deep waters again in order to spawn.

The author is of the opinion that the movement from deep to shallower water in summer should be regarded as a feeding-migration, since the great concentration of plaice in deep water causes an acute competition for food amongst the fish when the water in summer becomes warmer and the need of food arises. The comparative scarcity of plaice in the Arcona Basin is explained by the great fluctuations in the salinity. The author supposes that the males are more sensitive to the decrease in salinity than the females which in summer to a large extent remain behind in the deep water to the north of Bornholm. In many cases a connection was established between a numerous occurrence of plaice and an inflow of warm water rich in oxygen. Conversely, the constant low temperature and lack of oxygen in the bottom water in the deepest part of the Bornholm Basin to the east of the island is regarded by the author as the reason for the scarcity and poor quality of the plaice in this locality. Sometimes also the plaice disappear from the localities to the north of Bornholm where they are otherwise wont to congregate in large quantities; in such cases the bottom water has proved to be comparatively cold and lacking in oxygen.

Eggs were found at the Swedish investigations to be scarce in the Arcona Basin and most numerous in the deep to the north of Bornholm, where the spawning ground proper is supposed to lie. Also to the east of Bornholm were found many eggs, but the author is of the opinion that they had been carried thither by the current. In March the great majority of plaice were spent.

The growth of the plaice examined by the Swedish investigators in 1919 and 1920 was found to be greater than that of the plaice examined by Reibisch in 1911, but the difference was small. In the deeper water to the north of Bornholm the growth of the plaice was greater than in the shallower water and in the Arcona Basin, which fact is accounted for by the supposedly better natural conditions for plaice prevailing in the first-mentioned locality. Similarly only 6 per cent. of the plaice to the north of Bornholm had abnormal otoliths, whereas the percentage was 39 in the Arcona Basin and 12 on the coast of Rügen and at Ystad.

2. Flounders. In general flounders were more numerous than plaice in the area investigated. During the spawning season (March—May) the flounders remained for the most part in the deep to the north and east

of Bornholm; they also spawned however in the Arcona Basin although their numbers there were smaller. In May they began to migrate up towards shallower water, especially the smaller fish (13—20 cm. in length). This movement increased in June and July and culminated in September. These migrations also are regarded by the author as feeding-migrations, although regulated by hydrographical factors. He points out that in the central Baltic the migrations are least extensive, since the flounders have there become accustomed to a shallow-water existence.

3. Dabs. Dabs were also everywhere numerous, least however in the Arcona Basin, especially during the spawning season. During this season (May—July) the dabs sought the deeper regions to the north of Bornholm (depth, 70—80 m.), but are thought to spawn also in the Arcona Basin. After spawning, the dabs sought shallower places, their upward migration coming to an end in the autumn. In winter (March) they were found chiefly in shallower water, being little disposed to movement and probably buried in the bottom. Also in the case of dabs their migrations are explained as feeding-migrations. Lack of oxygen and fluctuations of temperature are thought to affect dabs less than plaice, for instance; nevertheless a high temperature (12° C.) is thought to restrict the migrations of dabs towards shallow water.

The paper is accompanied by a good chart, illustrating the position of the stations, and many tables which show what material has been at the author's disposal. Unfortunately it constitutes in many cases too slender a foundation to bear the far-reaching conclusions drawn by the author. It is to be hoped that future investigations will show how many of the hypotheses put forward by the author can bear a closer test. Against his explanation of the upward migration to shallower water as a pure feeding-migration may be opposed the fact that both THULIN and the present reviewer have found comparatively more abundant food in the deeps, abandoned by the plaice in summer, than in shallower water.

In the paper published in 1926 the author discusses the question as to whether such great changes can be said to have taken place in the plaice stock at that date as to call for the introduction of measures directed against possible overfishing. In addition to the material furnished previously, new material obtained in 1923 and 1925 is made use of in this paper; on this basis the author shows that the average size of the plaice in 1925 was 4 -6 cm. higher than that of the plaice of corresponding age in 1921. (In Figs. 1 and 2 the growth curves are traced for March 1922 and June 1919 for comparison with the curves for September 1921 and 1925; we must however remember that approximately a whole growth period lies between March and September, and a half period between June and September, for which reason a comparison is unjustified.) It is shown at the same time that the 1914 and 1916 year classes were numerically predominant over the other year classes during the years 1919—22; in 1925 on the other hand it was the 1920 and 1921 year classes that were numerically predominant over all the other year classes. Attention is also drawn to the fact that the percentage of plaice with abnormal otoliths in 1925 was only 2.3, as against 15.3 in March 1922 and June 1919; whereas in 1925 abnormal otoliths were only found in plaice over 7 years of age

they were in 1922 found in plaice which were only 4—5 years old. The author explains both this fact and the greater rate of growth among the plaice as a result of the intensive fishery and the consequent better food conditions for the plaice, and in this he is undoubtedly correct. By comparing samples from 1919 and 1925 the author finds a similarly increased rate of growth among dabs.

On pages 6, 7, is discussed the fact that whereas the plaice were very numerous on the coastal banks round Skåne and off Rügen before the intensive fishery commenced off Bornholm (1921—22) they have later partially disappeared from those localities. This fact is explained by the author as follows: prior to the commencement of the intensive fishery, the then existing overpopulation and the consequent acute competition for food forced the plaice to disperse over areas where less favourable conditions prevailed, e. g. lower temperature and salinity. After the intensive fishery had thinned out the stock, this dispersal was no longer necessary, there being now room enough in the deep localities where the hydrographic conditions were favourable. The present reviewer however thinks it to be a more probable assumption that the intensive fishery was the direct cause of the plaice stock in the shallower water being greatly thinned out rather than that the plaice abandoned their seasonal migrations to the shallower water on account of the fishery, all the more because it is here that the hydrographic conditions in summer are usually more favourable than in the deep.

To the question discussed at the beginning of his paper the author gives the reply that, although overfishing cannot be said to have occurred yet, the more rapid growth is nevertheless a warning against postponing measures for the preservation of the fishery until a too remote date.

This paper also is accompanied by a chart showing the position of the stations, and the material is arranged in tables. In neither of the papers however do we find any information as to the fishing appliances employed for catching the fish (saving trawl, otter trawl, size?). This point is surely of very great importance if the material in the two papers shall be used for future comparisons. H. Blegvad.

C. F. Hickling. The Natural History of the Hake. Parts I and II. Ministry of Agriculture and Fisheries. Fishery Investigations. Series II. Vol. X. No. 2. London 1927.

Mr. Hickling is to be congratulated on having produced a report in which the scientific treatment of the data is controlled by the experience of the practical fisherman. His own many voyages on steam trawlers under actual fishing conditions have given a point of view not available to compilers of other men's data and observations no matter how carefully collected. In this paper he traces the distribution of the hake and the course of the fishery in different regions and at different seasons throughout the year, illustrating this with quarterly charts of the density distribution in 1923 and 1924 as shown by the fishery statistics. In winter the hake have, in general, retired to the deep water at the upper margin of the Atlantic Slope in the neighbourhood of the 100 fathom line. From

this reservoir with the advance of the year a migration landwards sets in, in which two impulses may be distinguished, the earlier, a spawning migration of large hake, to waters of 60 to 80 fathoms, starting in March to the south-west of Ireland and passing as a wave up the west coasts of Ireland and Scotland. The later, a feeding migration of smaller hake, starts with the rise in temperature of the coastal waters, penetrates into shoaler water than the spawning migration and reaches its maximum in September and October at a time when the spent fish of the earlier migration are withdrawing to the deeper areas. The migration of the smaller hake is compared by the author to the general inwandering of oceanic drifting organisms, but the connection between a purely passive drift and an active migration is not very clear. He does not refer to the close parallel furnished by the mackerel with its "spring" fishery for large spawning fish and its "harvest" fishery in shallow water for smaller fish not yet mature.

A large part of the paper deals with the food and feeding habits of the hake and is based mainly on the author's personal observations. The hake, it appears, is almost exclusively a nocturnal and pelagic feeder, remaining quiescent by day on the sea bottom. It is only by day that it can profitably be fished for by steam trawlers, except in the case of concentrations of spawning fish which have ceased to feed, when good hauls may sometimes be made by night. Line fishing, on the other hand, is only carried on by night, in mid-water.

The food of the large and medium hake varies according to the season and locality. In deep water near the Atlantic Slope it consists mainly of the Blue Whiting (*Gadus poutassou*) supplimented by squids, *Caranx*, small hake and other pelagic forms. In shallower water mackerel and herring predominate but other fish, including small hake, and cephalopods are also taken. Very small hake feed largely on Euphansians and other crustacea.

The fact that hake brought up from deep water usually have their stomachs everted through the mouth made food investigation very troublesome and necessitated the examination of very large numbers of fish before sufficient data could be obtained. The proportion of fish in which eversion takes place varies with the depth and this has also to be taken into consideration when comparing hauls from different localities.

The inquiry was pursued further into the food of the hake's food and an interesting connection between the presence of swarms of *Meganyctiphanes*, on which the Blue Whiting feeds, and the concentration of hake in the same area is shown to be probable.

Amongst other points brought forward in the paper is the belief, prevalant amongst trawlermen, that increased landings or "gluts" of hake coincide with the date of full moon, and some statistical evidence is adduced in support of the alleged coincidence, the suggestion being made that there may be a periodic concentration of hake for spawning purposes corresponding to the lunar period.

The paper is very fully documented, the appendix containing many tables of the landings of large and small hake at various dates and in various regions, of surface temperatures from the regions under discussion

and of the results of the examination of stomachs both of hake and Blue Whiting.

Further instalments dealing with other aspects of the life history of the hake are promised by the author and may be expected to add considerably to our knowledge of a fish which is one of the mainstays of the trawling industry. G. P. F.

H. O. Bull. Studies on conditioned Responses in Fishes. Part I. Journ. of the Mar. Biol. Assoc. Plymouth, XV, 2, pp. 485—533, 1928.

In this paper Mr. Bull reports on some interesting experiments on sensory discrimination and habit formation in fish.

First the temperature discrimination of the blenny (*Blennius gattorugine*) was studied by means of an ingenious device (for the details of which I refer to the paper), by which it was possible during a few seconds to raise the temperature of the water in a jar in the aquarium in which the fish was living. At the beginning of the experiments the fish did not show any reaction when the temperature of the water was raised 3.5° C. But then during some time a piece of food was thrown into the aquarium, fifteen seconds after the water had been heated. In this way the rise in the temperature of the water became associated with the being fed, so that after 42 of these experiments the fish began to react on the heating of the water, i. e. it came out of the jar to the feeding place, before food was thrown there. By this method it was also possible to study the minimum rise of temperature that was perceived as such by the fish. While at first no reaction was obtained at a rise of 1° C. or less, by continued training reactions were obtained even at changes of only 0.4° C. And when at first the reactions followed at about 30 sec. after the stimulation, afterwards the average reaction time came down to 10 sec. with a minimum of 4 sec. Another blenny could be trained in a very short time: after 8 experiments with an average rise of the temperature of 2.6 ° C. the habit was already formed, and after a few days reactions were shown at a rise of temperature of 0.5° C.

In a similar way other sensory discriminations in fishes were studied. The faculty of perceiving small changes in the salinity of the water was studied by a device, that made it possible to lower this salinity by a few $^0/_{00}$, care being taken not to change the pH, the alkali reserve or CO_2 tension. While again at the beginning a change in the salinity did not give rise to any reaction, after about 40 experiments an association was formed and the fish came out for food at the perception of the change. The smallest change at which the reaction was shown was a diminution of the salinity of 3 $^0/_{00}$, the salinity of the water being about 37 $^0/_{00}$.

A habit based on vibratory perceptions was formed in the wrasse (*Crenilabrus melops*) by means of an electric tuning fork, attached to one end of the aquarium. Here the reaction was the opposite to that of the blenny: the wrasse, which normally swam round in the aquarium had to enter a bottle to take food. After 20 experiments in which the sounding of the tuning fork had been followed by feeding, the fish went into the bottle and waited for food, as soon as the tuning fork was sounded. Experiments with a submerged telephone however had no succes.

Finally in a dark room experiments on vision were made. A *Labrus bergylta* in some 20 experiments learned to seek for food in a special place in the aquarium, when an electric lamp above it was turned on. Then it was investigated whether the fish could learn to distinguish between the light from one and from two electric bulbs, no food being given when two lights were turned on. In about 50 experiments the fish learned to react positively to one light, and after some 40 more experiments the discrimination was sufficiently formed and no reaction followed when both were turned on. But the habit was totally lost after an interruption of 10 days. An attempt to train the fish to react positively to a single intensity of the light and negatively to a double one however had no success, and even with greater differences in the intensity the result was not very conclusive.

That similar experiments on colour vision gave good results need not surprise us, the colour vision of fishes being already sufficiently proved.

While in all these experiments food was used as an incentive for the training, in another series sense impressions were associated with an electric shock. When the shock was immediately preceeded by the lighting of a green lamp, after 20 experiments the reaction took place at the perception of the light alone. In this way too a discrimination between different colours could be shown. An eel formed a similar association between the vibration of an electric buzzer in the aquarium and the electric shock.

While readily acknowledging the ingenuity of the devices and the rigorous nature of the methods used in his experiments, I have to raise some objections of a more theoretical nature against this paper of Mr. Bull. The author is an admirer of the work of Pavlov on conditioned reflexes and expresses himself throughout this paper in Pavlovian terminology (in which I intentionally did not follow him). If the difference were only, that Mr. Bull speaks of "conditioning" an animal where I speak of "training", and calls the reward during the training an "unconditioned stimulus", this difference would not be very important. But I believe Mr. Bull is wrong, when he calls the reactions shown by his animals "reflexes" (or, more precisely: "responses", a term which, however, for him seems to be practically synonymous with reflex, vide p. 489). When the smell of the food or the hearing of the "conditioned" sound produces a secretion of saliva in a Pavlov dog, we may speak of a "reflex", although it is not at all certain, that the phenomenon is not of a more complicated nature than a simple reflex and that e. g. no memory images play a rôle in it. But when a wrasse on the perception of some sound or vibration swims to a bottle in the aquarium, enters it, and waits there till some food has been given, its behaviour implies so much of memory and anticipation and certainly of active striving, that the use of the term "reflex" seems out of place, so long as any value is attached to preserving the meaning of well defined terms. And Mr. Bull has certainly no right to think his work superior to all that is done in the field of sense physiology and habit formation of fishes (as he seems to do), only because the latter is "of a subjective nature and thereby open to conscious or unconscious bias" (p. 486), and so to ignore it (as he does). Much work equally good as that of Mr. Bull

has been done in the same field by students who did not use the Pavlovian terminology, nor tried to extend the idea of conditioned reflexes to this kind of behaviour. J. A. Bierens de Haan.

Alf. Dannevig. The Rearing of Lobster Larvae at Flødevigen. Report on Norwegian Fishery and Marine Investigations. III. No. 9. 1928.

This is an interesting account of the results of experiments made in 1926—27. Mr. Dannevig began by using an apparatus similar to that employed by Dr. Mead, but he discarded this in favour of the hatching boxes so long employed by him in cod-hatching and finally in 1927, he used an elaboration of this method which he found to ensure rapid renewal of the water and cleanliness. He tried various foods and got the best results from the use of ox liver.

The results were comparatively satisfactory and in some of the experiments were much better than those got by his predecessors. But it is manifest, as we found from our attempts at Cullercoats, that a considerable loss takes place at two periods. Even under the most favourable conditions the transport of the berried lobster is accompanied by a deterioration, for the number of larvae hatched only amounts to about 1000 per berried lobster.

During the first two stages the rearing is accomplished with little loss, but with the approach of the 4th stage a great decrease in numbers occurs in all artificial methods. In Mr. Dannevig's 1927 results the larvae liberated were just over a thousand per lobster, and the survival to the 4th stage was about 14 per cent. of the larvae collected. Another feature must not be forgotten, namely that under confinement growth is retarded and the effect may be engendered in the early history.

It is obvious therefore that before lobster hatching can be recommended as a means for improving a Fishery, it must be designed on a scale commensurate with the population involved, and above all it must show a great improvement on the death rate under natural conditions. A loss of 86 per cent. during the first two or three weeks of free life could not be fitted into the most liberally conceived curve of death-rate of the species. It is more than probable that the hatching under natural conditions is very much more productive, and that the inverse of the above figure is nearer the truth of a survival of the larvae in the sea. A more biologically sound method for improving or maintaining a lobster fishery is the protection of the berried female, for thereby the egg-bearing females are allowed to complete their task in demonstrably better than artificial conditions. A. M.

C. Amirthalingham B. Sc. On lunar periodicity in Reproduction of *Pecten operculatis* near Plymouth in 1927—28. Journal of Marine Biological Association, N. S. Vol. XV. No. 2. April 1928.

On the evidence offered in this paper, the Queen, *Pecten operculatis*, must be added to the growing list of organisms which exhibit a lunar periodicity in their reproductive phenomena.

The samples used in the present research were usually of ample size, and taken at intervals of rarely more than a week. A good description of the naked-eye and microscopic appearance of the hermaphrodite gonad is given, and of the morphological and cytological criteria which form the basis of the statistical "maturity stages" used by the author. Especially admirable is the use of successful artificial fertilisation as a test of ripeness.

Ova and spermatozoa are apparently not shed by a single individual at the same time; in 90 per cent. of cases the hermaphroditism is protandrous. The early development of the oocytes and spermatocytes is relatively rapid, but the ripening of a new crop of sexual products takes longer than a lunar month.

The results of the examination of samples of Queens from February 1927 to March 1928 are set forth in a table and a graph. The curves for the percentage of ripe males and females, respectively, show a very close correlation. The *peaks* in the curves, of which there are 13, show a correlation with the moon's phases, such that 9 of them occur between the dates of the first quarter and full moon. The correlation, however, naturally breaks down during the non-spawning months, from July to November, when the percentage of Queens with ripe gonads is very low, or even nil.

These non-spawning months are further analysed in a separate table and graph. Unfortunately, the data here deal with the percentage of individuals with "developing gonad", a condition not defined in the text. The curve for "percentage of individuals with developing gonad", falls at the time of full moon, and the author suggests that the same essential cycle of changes is taking place during the non-spawning, as during the spawning months, with the difference that, during the non-spawning months, the sexual products reach a certain stage of ripeness, but then degenerate, whereas, during the spawning months, these advance to full ripeness, and are shed at intervals of a lunar month. In fact, he concludes that this periodicity in reproduction is due, not to any external factors, but to an internal factor, namely, a physiological rhythm. In reaching this conclusion, he discusses the possible effects of tidal movements, direct moonlight, and periodicity in feeding, but dismisses them as unlikely. He describes experiments made by placing Queens in covered cages, by which the direct effect of moonlight might be tested, and made rough measurements of the volume of the stomach contents, to test for a periodicity in feeding; both experiments were negative.

The reviewer feels that the author is on safe ground in suggesting a physiological rhythm, which is making itself apparent in this, and other similar cases of lunar periodicity in reproduction. Not the least attractive features of this paper are the excellence of the style, and the clearness of the exposition. C. F. H.

J. H. Orton. On Rhythmic Periods in Shell-growth in *O. edulis* with a Note on Fattening. Journ. Mar. Biol. Assoc. XV 2. pp. 365—427. 1928.

The present paper is based mainly on observations of shell-growth made during the author's study of oysters in the Upper Fal Estuary in

1925, and continued more closely during 1926 and 1927. They are supplemented by data relating to other oyster beds, less complete but covering a considerably greater period. The growth referred to here is the seasonal production of a thin marginal extension, or "shoot", which may increase the area of each valve by a strip 1 cm. or so across, and when thickened may increase the weight of each valve by $^1/_{10}$ of the weight of both valves together. As the author points out, however, from the evidence of sections it is more than probable that thickening layers inside the shells are laid down at the same time or just after increase in area takes place.

Dr. Orton shows that during the warm years 1925 and 1926, and in 1927, which was below the average in temperature, two distinct periods of shell-growth occurred; one in spring the other in autumn, separated by the summer breeding period. He found the same sequence also to hold true for the Yealm estuary and for the Blackwater River beds on the more distant East side of England, but variations with season and locality occur in the commencement of shell-growth and spawning; thus in the Blackwater the spring growth begins later and may overlap the breeding period, which on the Fal is distinct. He concludes therefore, that one shell growing period preceding, and one following the breeding period can be regarded as a general rule for all estuarine situations on the English Coast.

Comparison of conditions over widely separated beds, and of the behaviour of oysters on them in normal and abnormal years, affords means whereby shell-growth may be correlated with external or internal conditions or a combination of both. A considerable portion of the present paper is devoted to a closely reasoned discussion of possible factors; temperature and salinity variations, food, light and alkalinity of the sea water, tides, and finally certain internal conditions are considered. It is concerning the first and last mentioned that the author is able to indicate conclusions with confidence; with the other factors data is lacking for more than an indication of probabilities. Correlated with later spring shell growth and an earlier breeding period on the Blackwater is a greater annual range of temperature with a later and more rapid rise of temperature in the spring than on the Fal. The autumn fall in temperature is earlier and more rapid, and autumn shell-growth also begins earlier on the Blackwater. A general conclusion regarding temperature relations is formulated, that shell-growth begins in the spring when 50° to 52° F. (10° to 11° C.) is attained on a rising temperature, and again in the autumn, but in association with some other factor, when the temperature falls from 60° to 57° F. (15.5° to 14° C.). Abundance of food at these times is postulated. The author discusses conditions in three general types of oyster bed, viz. in an estuary such as the Thames, in a "deep sea" bed, and in an intermediate type of open estuary, such as the Fal. He shows how rise and range of temperature may influence the incidence and duration of shell-growing and breeding periods, and suggests that the large shells of deep sea oysters may not have required many years for their growth, having been exposed to shell-growing temperatures (i. e. between 50° and 60° F.), for longer periods each year than occur in estuarine situations.

Evidence is cited indicating a probable abundance of food when shell-growth is taking place, and the author considers that the attainment of

a temperature of about 50° F. is necessary for active feeding, as well as for beginning of spring shell-growth, so that the two begin together. It is of interest to note here that Galtsoff (1928), concludes from laboratory experiments that current begins to flow in the mantle cavity of *O. virginica* at 8° C. Webb too, in a long series of experiments on the cleansing of *O. edulis*, (at present unpublished), established by physiological and bacteriological tests that active feeding begins at 46° F. (7.8° C.) and continues up to at least 65° F. The probability of active feeding from the first beginning of shell-growth is therefore confirmed.

Regarding internal conditions, the author found that new shell-growth may be formed during almost any of some thirty states of the gonad which he is able to recognise, but that it is deposited least in oysters which in the spring are about to produce ova, and in those which are fattening. The former condition occurs normally when the temperature remains at about 59° to 60° F. (15° C.), whereas fattening takes place after the autumn shell-growing period. These two conditions appear to be definitely antagonistic to shell-growth.

With regard to fattening, the author noted in 1927 that it began early in the Blackwater but on the Thornfleet beds alone. Indicating the dependance of oysters for fattening on an abundance of vegetable organisms during the late summer and autumn, he suggests that dumps of decomposing *Crepidulae* may possibly have replenished the supply of phosphates and nitrates on that bed; and further, should a connection between such fattening and these dumps be established, then a prediction made some years ago of a "manuring" of the sea may become economically feasable.

A reference to shell-growth in spat is not included in this paper. During the first season's growth, antagonism of sex development stages can hardly operate, at any rate markedly. It is of interest therefore to note that shell-growth does occur at temperatures over 60° F. in oyster spat, which should prove to be good material for examining the influence of external factors.

Dr. Orton has made thorough and comprehensive use of the data at his disposal, and the present paper marks a definite advance towards an understanding of all the functional activities of the oyster.

H. P. Sherwood.

Ikusaku Amemiya. Ecological Studies of Japanese Oysters, with special reference to the Salinity of their Habitats. Journ. Coll. Agric. Imp. Univ. Tokyo. Vol. IX, No. 5, 1928.

The experimental work described in this paper is concerned primarily with the influence of salinity not on mature but on embryonic stages of the commoner species of Japanese oysters. The method of investigation is substantially that previously used by Dr. Amemiya with *Ostrea edulis*, *O. angulata*, and *O. virginica*. He observed the development, where possible, of artificially fertilised ova, divided among media differing in salinity by small amounts from Ca. 5 per thousand to Ca. 55 per thousand. In the case of *O. denselamellosa*, a hermaphrodite species closely resembling *O. edulis*, which does not easily yield artificial fertilisations, early embryos

were instead taken from parent oysters. The temperature was kept as nearly as possible to that usually observed in the natural habitat of each species at its spawning time. In this way results were obtained ranging from 100 % of well developed embryos down to none, the effect of too high or too low salinity being to retard or prevent segmentation, and ranges indicating the limiting and optimum salinities for the development of each species were arrived at. The stages and rate of development of *O. gigas* were observed not only at 25° C. but also at 16° C. At the lower temperature the time taken to reach the shelled stage was ca. 50 % longer, but the range of salinity available was slightly greater. In unfavourable salinities special features of abnormal forms were noted; some consisting of small blastomeres arranged not unlike the cells of a yeast colony, referred to as "Knospenfurchung", others being "partial larvae". Clear drawings of these and of normal embryonic stages are included. Observations were made and data collected bearing on habitats, and on salinities, and useful introductory notes on the identity and biology of Japanese oysters appear, illustrated by good photographs.

The optimum salinities for development fall into two groups. Three forms inhabiting muddy shores between tide marks, where the salinity may vary from ca. 10 per thousand to ca. 30 per thousand, are *Ostrea gigas*, *O. sikamea*, (a variety of *O. gigas*), and *O. rivularis*. They have a limiting range in common, between ca. 8 per thousand and 35 per thousand with an optimum of ca. 18 per thousand to 25 per thousand. The other forms have optima corresponding to the normal salinities of their habitats, viz., ca. 28 per thousand to 35 per thousand. The limiting range for *O. denselamellosa* is shorter than for the other species; ca. 21 per thousand to 41 per thousand. This oyster lives on gravelly bottoms below low water and is not therefore exposed to extreme variations of salinity. *O. spinosa* and *O. circumpicta* have wider limiting ranges; that for the last named being from ca. 15 per thousand to over 50 per thousand, its habitat reaching from high tide mark to several fathoms, in rocky areas. In marked contrast with *O. denselamellosa*, *O. spinosa* lives high on the shore and is covered only for a comparatively short period at flood tide. Under exceptional conditions individuals of these two species may be exposed to a wide range of salinity from 10 per thousand to over 50 per thousand, owing to dilution by rain or excessive evaporation in rock pools and crevices. The embryonic stages, therefore, are well adapted to the habitats of each species. It may be noted that adult individuals show a greater toleration to extremes of salinity.

The author tested the influence of a parent oyster's habitat on the favourable salinity range for development of it's offspring by exposing groups of oysters which were ready to spawn to several different grades of salinity for one or two days. He concluded on examining the embryos from each grade that "the grades of salinity in which the parent oysters live exercises no direct influence whatever upon the development of their offspring". This is understood to mean the exact grade in which oysters happen to be at the time of spawning, for those tested can hardly be regarded as having lived in the given salinities after an immersion of only one or two days. An interesting extension of the work would be a comparison

of individuals of a single species, such as *O. circumpicta*, with its wide distribution zone, after being transferred to an exposed rock pool from below low water, with those already in the higher zone and with those remaining covered, with a view to ascertaining how soon a change of habitat influences the range of salinity available for development of their larvae.

Similar difficulties occur in raising larvae of all these oysters artificially beyond the shelled veliger stage, as with *O. edulis*. There appears at any rate to be some latitude as regards salinity, and much can be said for lack of suitable food as a cause of failure.

Notes are included on behaviour of larvae during development, and on the spawning process, which was observed both under natural conditions and in the laboratory. In carrying out this work Dr. Amemiya has made an interesting contribution to our knowledge of the oyster in relation to its environment.

H. P. Sherwood.

Correspondence.

The Editor, Journal du Conseil.

Mortality among Fal Oysters 1924—26.

In a review in the Journal du Conseil (III, 2, p. 272, 1928) of a paper on "Observations on the Fal Estuary Oyster Beds during 1926, including a Study in Over-fishing" by the present writer, the reviewer (R. Spärck) legitimately draws attention to the omission of observations of mortality in that paper. I therefore write this note to supplement the necessarily summary report referred to.

During the course of investigation on the Fal in 1924—1926, observations on mortality were made especially at the beginning of the dredging seasons in 1925 and 1926. Mortality was found to have been mostly very slight on the natural oyster beds during both these years and was adjudged not greater and probably less than that observed in 1924 (see page 68, Report on a Survey of the Fal Estuary Oyster Beds, November 1924 etc. J. H. Orton, 1926, Falmouth). Definite figures were not obtained, as the order of the mortality could be estimated and referred to previous observations merely by inspection of the numerous hauls being made at all parts of the beds. The mortality was estimated to be less than 5 % on the main parts of the beds, i. e. the Banks and Edges, but, as in 1924, at a higher and indeterminate figure in the River Beds. The relative constancy of the mortality in the period 1924—26, rendered this factor unimportant, though necessary, in the discussion on over-fishing in the paper referred to.

Marine Biological Laboratory,
Plymouth, October 29th 1928.

J. H. Orton.

Notiz

zur Arbeit:

Die Wasserbewegungen im Gebiete der Gibraltarstrasse.

Auf p. 156 im Journal du Conseil, Vol. III, No. 2 (1928) muss es in der Fig. 9 rechts in der Unterschrift heissen

statt Dana 1117: richtig Dana 1138.

Das Strukturbild für diese Dana-Station 1138 ist gezeichnet auf Grund der Generalmittel (standard means) für die Verankerungsperiode vom 8.—10. X. 1921. Diese Generalmittel sind in jener Arbeit von mir nicht veröffentlicht worden, obwohl dies vielleicht zweckmässig gewesen wäre; sie werden daher hier noch gegeben.

»Dana« 1138.

Meter	t°	S ‰
0	20.32	36.43
50	17.23	.29
100	14.77	.58
125	.13	37.34
150	.01	.53
175	13.55	.77
200	.44	.83
225	.26	38.01
250	.17	.03
300	.06	.24

Die mir von Herrn Dr. Ramalho, Lissabon, freundlichst gemachte kritische Bemerkung ist durchaus berechtigt, dass in der Fig. 9 rechts die Beobachtungen einer Dauerstation (Dana 1138) combinirt sind mit den Beobachtungen einer einmaligen Station (Thor 61), was bei den starken vertikalen Oscillationen der Sprungschicht bedenklich ist: aber für einen Wintermonat ist nur keine Verankerungsstation oder Dauerstation innerhalb der Strasse bekannt. Es ist — leider — so, dass selbst einfach erscheinende Vorgänge in der Natur fast immer bei näherer Kenntnis viel verwickelter werden, als man annahm.

Hamburg, den 1. 12. 1928.

G. Schott.

Current Bibliography.

Prepared by the Editor with the assistance of Miss Thursby-Pelham.

NOTE. The scope of the Bibliography is limited in the main to the area covered by the Council's activities, but there are included papers of general interest relating to other areas in the North Temperate and Arctic regions and exceptionally elsewhere. Limnological references are not as a rule given, but papers relating to brackish waters and to salmon and freshwater fish studied by the Council are included.

The classification of entries follows in a general way that adopted in Dr. ALLEN's Selected Bibliography published in Vol. I, Nos. 1 and 2 of the Journal, and since reprinted.

Subscribers and those on the distribution list will receive regularly upon application to the Administrative Secretary copies of the Bibliography printed on one side of the page only, for use in making up card indices.

The Editor will be glad to be advised of emendations and additions to the Bibliography.

Physical and Biological Conditions in the Sea.

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